

**NUTRITIONAL EVALUATION OF WHEAT BRAN FROM ABRASION MILLING IN
BACKGROUNDING DIETS FOR CATTLE**

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By

Alin D. Friedt

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ABSTRACT

Two trials were conducted to evaluate the nutritional value of abrasion milled wheat bran (WB). In Trial 1, 312 Angus steers ($303 \pm 65\text{kg}$) were randomly assigned to 1 of 24 pens and fed 1 of 6 diets in a 2x3 factorial design. Treatments included 2 levels of condensed liquid whey (CLW) (0 and 4.6%) and 3 levels of WB (0, 14 and 28%). Diet 1 consisted of 31.8% rolled barley, 40.6% brome grass hay, 13.5% barley silage, 7.3% corn/wheat blend DDGS and 6.9% supplement (DM basis). Diet 2 was identical to diet 1 except 4.6% of the barley was replaced with CLW. In the remaining diets, at each level of CLW, WB replaced barley at 14 and 28% (DM basis) ($P>0.05$). No influence ($P>0.05$) of CLW or any WB by CLW interaction was seen on any parameter. Dry matter intake (DMI) was increased ($P<0.01$) in diets containing WB. Average daily gain was not ($P>0.05$) affected by WB inclusion, however gain:feed was reduced ($P<0.01$).

Trial 2 used 5 Angus heifers ($584 \pm 40\text{kg}$) in a Latin square design to evaluate the effects of WB on rumen fermentation and nutrient digestibility. The control diet consisted of 36% barley silage, 24% grass hay, 8% supplement and 32% rolled barley (DM basis). Wheat bran replaced barley at 8, 16, 24 and 32% of the diet (DM basis). There was no ($P>0.05$) effect of treatment on DMI, rumen pH, ammonia-N levels or fluid and particulate passage rate. Feeding WB caused a linear increase ($p<0.05$) in acetate concentration and decreased ($P<0.05$) DM, OM and GE digestibility in a linear fashion. Digestibility of NDF and ADF decreased ($P<0.05$) quadratically as WB inclusion increased. Diet digestible energy content tended ($P=0.06$) to decrease quadratically as WB increased. Digestibility of CP, total nitrogen (N) excretion and urinary N were not affected ($P>0.05$), but fecal N was increased ($P<0.05$) in a linear fashion. The results indicate that the energy value of WB is lower than barley grain which leads to decreased feed

efficiency and diet digestibility in backgrounding rations, which indicates that inclusion of WB will be price dependent.

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LIST OF ABBREVIATIONS

ADF	Acid detergent fibre
Ammonia-N	Ammonia Nitrogen
BW	Body weight
CLW	Condensed liquid whey
CP	Crude Protein
d	Day
DDGS	Dried distillers grains with solubles
DM	Dry matter
DMI	Dry matter intake
h	Hour
kg	Kilogram
<i>l. dorsi</i>	<i>Longissimus dorsi</i>
mm	Millimetre
mL	Millilitre
N	Nitrogen
NDF	Neutral Detergent Fibre
NE _g	Net energy gain
NE _m	Net energy maintenance
OM	Organic Matter
P	Probability
SAS	Statistical analysis system
SD	Standard deviation
SE	Standard error

TS	Thin stillage
VFA	Volatile fatty acid
WB	Wheat bran
WDG	Wet distillers grains
wt	Weight
%	Percent

1.0 GENERAL INTRODUCTION

As of September 2010, the Canadian government mandated that there must be at least 5% ethanol in gasoline (Canadian Renewable Fuels Association, 2010). The Canadian provinces of British Columbia, Alberta, Saskatchewan, Manitoba and Ontario have instituted their own ethanol mandates ranging from 5 to 8.5% (Canadian Renewable Fuels Association, 2010). British Columbia and Manitoba also have existing mandates for biodiesel (Canadian Renewable Fuels Association, 2010). As these mandates come into effect and the percent inclusion of ethanol in fuel continues to increase, there will be a need for increased ethanol production in Canada if mandates are to be met domestically (Canadian Renewable Fuels Association, 2010). This will lead to an increase in the number of plants producing ethanol and may possibly lead to expansion and/or retrofits that lead to increased efficiency within an existing plant.

As production of ethanol increases, both domestically and worldwide, the number and supply of by-products from this industry will also increase. While the most commonly used ethanol substrate in the United States and eastern Canada is corn, in western Canada wheat is commonly used for ethanol production (Agriculture and Rural Development, Government of Alberta, 2007). The grain type fermented influences the composition of the by-products produced. Many publications exist on the feeding value of ethanol by-products produced from fermentation of both corn and wheat (Gibb et al. 2008; Leupp et al. 2009; Spiehs et al. 2009; Beliveau and McKinnon, 2009). These by-products include dried distiller's grains with solubles (DDGS), as well as wet distiller's grain (WDG) and thin stillage (TS) (Stock et al. 2000).

One way that plants fermenting wheat for ethanol may increase efficiency and ethanol yield without large scale expansion is abrasion milling of grain prior to roller milling or grinding

(George et al. 2010). This has the potential to remove some or most of the bran portion of the grain. This bran layer does not contribute to ethanol yield as it is generally high in fibre and non-starch polysaccharides and low in readily fermentable substrates (Bartnik and Jakubczyk, 1989). Removal of bran leads to a higher percentage of ethanol in the beer produced by the plant (Sosulski and Sosulski, 1994; Sosulski et.al. 1997). Sosulski et al. (1997) stated that debranning will increase plant throughput by 8 to 23% depending on how much of the kernel is removed. Abrasion milling or debranning generates an additional by-product, wheat bran (WB), along with the more traditional by-products of DDGS, WDG and TS.

Although there has been research published on the value of corn bran derived from ethanol pre-processing in ruminant diets (Janicek et al. 2007; Schingoethe et al. 2009), there is comparatively little research on the value of wheat bran as a feedstuff or on how debranning changes the composition of other ethanol by-products. Furthermore, the majority of existing literature is outdated and based on wheat bran derived from the flour milling industry. Although bran derived from the flour milling industry may have similarities to bran derived from abrasion milling prior to ethanol production, there will be differences. This is because the varieties of wheat used for each process are different and the amount of kernel removed in each process will differ. The objectives of this review are to provide an overview of the literature on the composition of wheat bran as well as its use in animal feeds, particularly as a feedstuff for ruminant animals. Ethanol production with and without front-end abrasion milling of grain will also be reviewed.

2.0 LITERATURE REVIEW

2.1 The Canadian Cattle Industry

The production of cattle is an integral part of Canada's economy. Statistics Canada reports that as of 2008 there were just over 86,000 farms and ranches in Canada with beef cattle (Agriculture and Agri-Food Canada, 2008). The western Canadian provinces play a very large role in cattle production with 41% of total Canadian beef cattle being located in Alberta (Agriculture and Agri-Food Canada, 2008). The majority of these farms are cow-calf operations but western Canada has an essential role in the feeding industry as well. According to Statistics Canada, over 75% of Canadian cattle in feeding operations are located in the western provinces (Statistics Canada, 2011). These large cattle inventories combined with substantial acres being used for crop production provide opportunity for use of many different by-product feeds in western Canadian cattle diets.

The cattle industry in Canada is based on the export of beef to other countries, the United States in particular. Traditionally, the value of currency in Canada has been lower than that of the United States (Klein et al. 2006). This combined with the fact that the price of cattle in Canada has been lower than the price of cattle in the United States, has made Canadian cattle an attractive option for U.S. cattle buyers (Klein et al. 2006). As the production of biofuel through fermentation of cereal grains continues to grow, there will be a higher demand for grain and the price will be driven up for cattle feeders in both Canada and the United States (Rosegrant, 2008). These cost increases in feed, as well as the rising Canadian dollar, eliminate the cost advantage for American cattle feeders to purchase Canadian cattle. This has negative effects on the entire Canadian cattle industry (Klein et al. 2006). The use of cost effective by-product feeds,

particularly those derived from the production of ethanol, is one management strategy that can help maintain the competitiveness of the Canadian cattle industry.

2.1.1 Grain-Free Diets for Cattle

The cost of feed is an important factor for both backgrounding and finishing calves. Reducing feed costs even by a small margin can mean large savings. In the finishing period calves must gain quickly and efficiently. In order to produce this efficient growth, highly fermentable diets including eighty to ninety percent concentrate are fed. In Canada, the most common concentrate used in feedlot diets is barley grain, while in the United States corn is more common. A great deal of research is currently being carried out on replacing these grains, in whole or in part, with other feeds such as DDGS. However, in order to maintain high performance in finishing diets, some grain must be included. The backgrounding period allows for more flexibility in diet formulation. Calves are not expected to gain as much per day and cheap and convenient feeding practices are sought after. Feeding by-product based diets that are completely devoid of grain can reduce cost while performance remains at an acceptable level.

Producers are adopting more extensive methods of backgrounding calves, such as pasture grazing in the summer and fall and bale grazing in the winter (Lardy, 2007). However, to keep performance at a desired level in these extensive systems, animal rations must often be supplemented with protein and/or energy (Berger et al. 2011). When grain-free diets are fed that are sufficient in energy, an alternate source of nitrogen may be beneficial. Research has shown that bulls fed grain-free diets and provided with an extra source of nitrogen had similar performance to bulls fed grain-based diets (Giri et al. 2000; Giri et al. 2005). When replacing grain with alternate energy sources, feeds with a highly digestible fibre fraction are often

desirable, such as DDGS (Schingoethe, 2006). Both corn and wheat DDGS have proven to be useful feed ingredients in ruminant diets, with levels up to 50% fed to finishing cattle with similar performance results to the control diet containing grain (Benson et al. 2005; Schingoethe, 2006; Gibb et al. 2008; McKinnon and Walker, 2008; Buckner et al. 2008). DDGS is an ideal replacement for grain because not only is it high in digestible fibre, it also has high levels of crude protein (CP) (Schingoethe, 2006). The widespread use of DDGS has led to a rise in its price, which is now very similar to that of barley. This leaves a need for investigation of other potential grain replacements for ruminant animals.

2.2 The Dry Mill Ethanol Process and Production of Byproducts

There are two production processes that can be used to ferment grain into ethanol. They are referred to as wet and dry milling. The dry milling process is most commonly used for production of ethanol from wheat (Figure 2.1). First, the grain is milled into flour. Milling increases the surface area available for fermentation. The flour is mixed with water and alpha-amylase and then heated to form a mash; this process is called cooking (Woerman et al. 2008). During the cooking process, the pH of the mixture is adjusted to 6.0 to allow the heat stable alpha-amylase enzyme to begin breaking down the starch to soluble dextrans (Bothast and Schlicher, 2005; Woerman et al. 2008). The mash is also heated to 100°C or higher in order to rupture the starch granules (Bothast and Schlicher, 2005). After the cooking process is completed, the mash is liquefied (Bothast and Schlicher, 2005; Woerman et al. 2008). The next step in the dry mill process is saccharification where pH is reduced to 4.5 and glucoamylase is added (Bothast and Schlicher, 2005). The purpose of this enzyme is to convert starch to glucose. Enough of this enzyme is added such that starch continues to be converted to glucose throughout the fermentation process. The mash is then fermented. Once in the fermenters, yeast is added

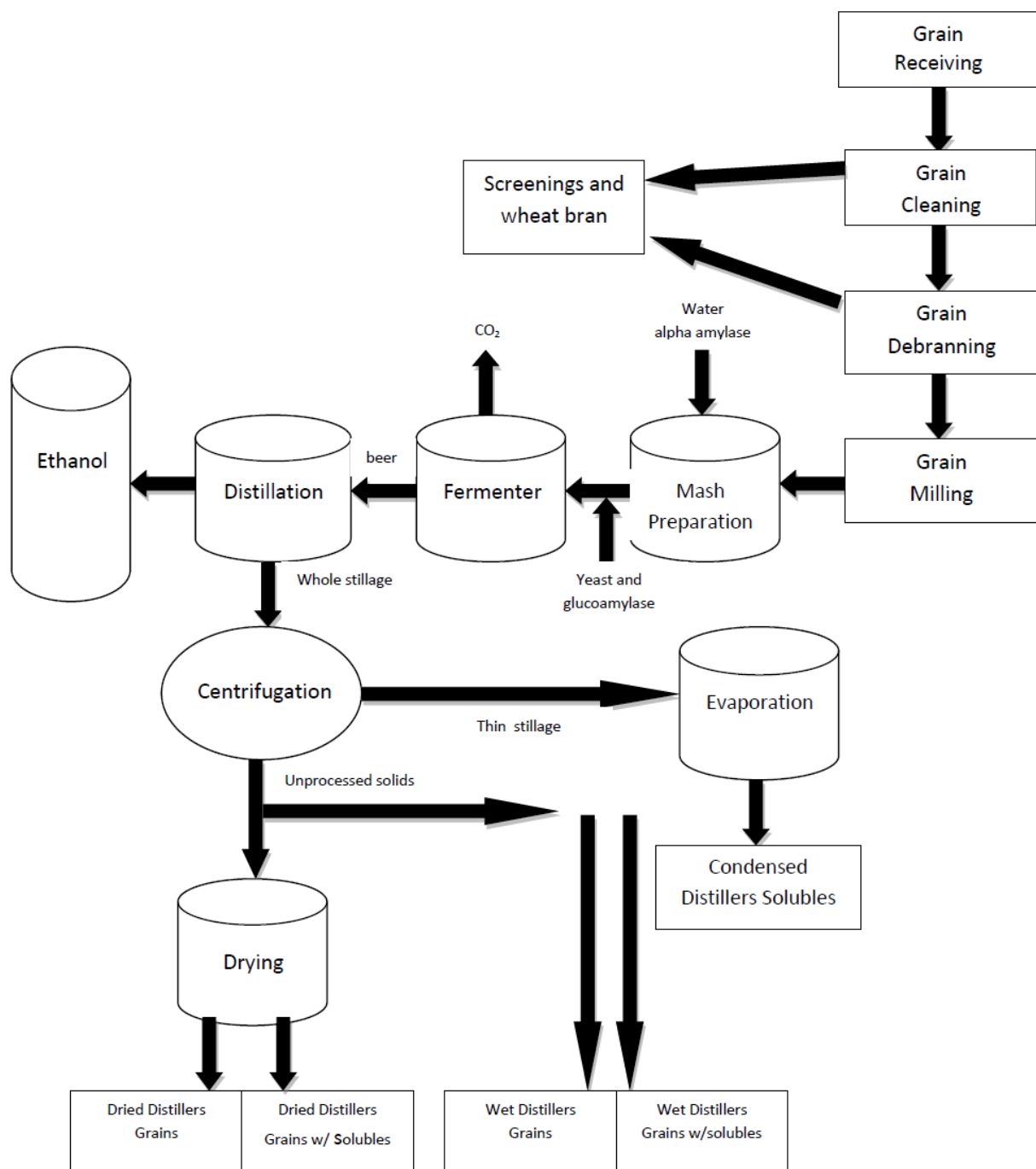


Figure 2.1 Dry Grind Ethanol Process with a Front End Debranner (Adapted from Perkis et al. 2008)

along with a nitrogen source to facilitate yeast growth (Bothast and Schlicher, 2005). Fermentation generally requires 48 to 72 hours to complete and the ethanol concentration at the end of fermentation is 10-12 % (Woerman et al. 2008; Bothast and Schlicher, 2005). Carbon dioxide is also produced at this step (Bothast and Schlicher, 2005). The next steps in the process are distillation and dehydration. In this process, the ethanol must be separated from both the water and solids that are left in the mash. Ethanol vaporizes at a lower temperature than water which allows most of the water to be separated from the ethanol. The last 5% of water must be removed with a molecular sieve system, which leaves virtually 100% ethanol (Bothast and Schlicher, 2005).

2.2.1 Frontend Debranning: Effects on By-product Production

The addition of a debranner to an ethanol plant adds an extra step to the process described above. After the grain is cleaned and before it is milled into flour, it enters the debranner. Inside the debranner, the outer layers of the kernel, which are high in non-fermentable materials such as structural carbohydrates, are removed. Most commercial debranning systems allow the operator to change the settings which dictates how much of the wheat kernel is removed in the process. The goal of debranning is to optimize starch throughput in the dry mill ethanol process. This means removing as much non-fermentable material as possible, while removing a minimal amount of the starchy endosperm of the kernel. Removal of too much of the endosperm will cause a decrease in the amount starch entering the fermenter and a potential loss in ethanol yield.

Some small-scale work has been done evaluating the effects of debranning of grain prior to ethanol production. In one study by Sosulski et al. (1997), it was found that plant throughput was increased by 8 to 23% when grain was pre-processed. This was due to the increased amount of starch being processed for the same weight of feedstock. Similarly, Sosulski and Sosulski

(1994) found that when several different varieties of wheat were debranned, plant capacity was increased by 20 to 26%. These small-scale studies also showed that when grain was debranned, ethanol concentration in the beer was increased by 14 to 17% (Table 2.1) depending on the type of wheat (Sosulski and Sosulski, 1994; Sosulski et al. 1997). Another finding was that the energy required to produce a litre of ethanol from debranned grain was significantly lower than that needed for grain which had not been debranned (Sosulski et al. 1997). However, these studies were done in a lab setting, not on a large-scale in a commercial ethanol plant. How debranning impacts ethanol production in a commercial setting has not been reported. In a commercial setting there are more factors that need to be taken into consideration. For example, economic analysis is required to evaluate if the increased plant throughput and increase in ethanol concentration in the beer compensates for the additional cost of running the debranning equipment.

Table 2.1 The effects of debranning on starch and protein content of wheat as well as on ethanol concentration in the beer

Wheat Class	Protein	Starch	Ethanol Concentration in the Beer
	% as is	% as is	% v/v
Unprocessed Grain			
HRS-Katepwa	15.09	53.63	12.68
CPS-Biggar	12.54	57.05	13.38
SWS-Fielder	13.02	57.02	13.77
Pre-processed Grain			
HRS-Katepwa	14.89	64.24	15.18
CPS-Biggar	11.88	66.82	15.41
SWS- Fielder	12.14	68.20	15.89

Adapted from Sosulski and Sosulski (1994)

2.3 Wheat Kernel Composition

Wheat is a very important cereal grain worldwide. It is widely used in both human and animal nutrition. In addition, wheat is becoming a more common feedstock for ethanol

production. Because of the nutritional importance of wheat, its chemical composition is well known. Wheat consists of many cell layers. The bran is made up of several cell layers whose function is to protect the interior of the seed and allow the seed to germinate (Pomeranz, 1987). The germ or embryo of the kernel gives rise to the seedling (Pomeranz, 1987). The starchy endosperm, which makes up the majority of the kernel, is required to nourish the seedling once food reserves within the embryo have been used up (Pomeranz, 1987). When discussing abrasion milling of wheat prior to ethanol production, it is important to have a clear understanding of the distribution of nutrients within the layers of a kernel of wheat. Understanding nutrient distribution will provide insight into the composition of both wheat bran and other distillers by-products produced in an ethanol plant with debranning equipment.

2.3.1 Pericarp

The bran portion of a kernel of wheat is comprised of several outer layers of the wheat kernel. The layers that constitute the bran are the pericarp or fruit coat, epidermis, hypodermis, intermediate cells, cross cells tube cells, and the testa (seed coat) (Pomeranz, 1987). According to Sramkova et al. (2009), approximately 53% of the pericarp consists of fibrous materials, mostly hemicellulose and cellulose. Much of the fibre in wheat bran is tightly bound to protein (Sramkova et al. 2009). Protein makes up about 16% of the pericarp. Carbohydrates constitute approximately another 16% (Sramkova et al. 2009). The pericarp is also very rich in vitamins and minerals, which comprise 7.2% of the pericarp, including high levels of potassium, phosphorus, iron, magnesium and cobalt, as well as B vitamins.

2.3.2 Aleurone

In the literature, the aleurone layer is nearly always discussed as one of the layers present in the bran because when wheat is milled for flour, the aleurone layer is removed with the pericarp. When abrasion milling is carried out for ethanol production, only a small percentage of the kernel is removed and the aleurone layer likely remains on the kernel and is not part of the bran. This also could be due to the fact that traditional data is based on hard wheat used to produce flour and not soft white wheat that is used for ethanol production. Greffeuille et al. (2005) found that when hard and soft wheat were milled to the same level, more of the aleurone layer was present in the bran of hard wheat than that of soft wheat. The aleurone layer is compositionally very different from both the starchy endosperm, pericarp and testa layers present in wheat bran. As a result the composition of milling by-products will be affected depending on whether the aleurone layer is present or not (Bartnik and Jakubczyk, 1989). The aleurone layer is very high in protein (33 to 45% CP on a DM basis), and similar to the pericarp, it contains a large portion of the vitamins and minerals found in the wheat kernel (Bartnik and Jakubczyk, 1989). This implies that wheat bran from abrasion milling may be lower in protein, vitamins and minerals if the aleurone layer is not present in the bran (Bartnik and Jakubczyk, 1989).

2.3.3 Germ

The germ of the wheat kernel is composed of the embryonic axis and the scutellum, which, as described above, is where the seedling germinates from and is nourished by after germination (Sramkova et al. 2009). It is found at one end of the kernel and contains 25% crude protein and between 8 and 13% fat (Sramkova et al. 2009). The germ also contains approximately 4.5% minerals and vitamins (Sramkova et al. 2009).

2.3.4 Starchy Endosperm

The starchy endosperm represents 75 to 86 % of the total kernel weight and contains three different types of cells, peripheral, prismatic and central, all of which store starch within a protein matrix (Pomeranz, 1987). The endosperm is about 88% starch and the rest is composed of about 1 to 2% fat and 12 to 13% protein (Sramkova et al. 2009; Pomeranz, 1987). Unlike the bran, the starchy endosperm is very low in fibre, vitamins and minerals. During milling, any starch that ends up in the wheat bran is derived from the starchy endosperm.

2.4 Nutrient Composition of Ethanol By-products

2.4.1 Traditional By-products: Dried Distillers Grains with Solubles, Wet Distillers Grains and Thin Stillage

Traditional by-products of ethanol production from wheat, DDGS in particular, have been studied in depth and the composition has been widely reported. Other ethanol by-products such as WDG and TS have also been studied, but not to the same degree as DDGS; this is most likely because these other by-products are not as widely available. Nuez-Ortin and Yu (2009) found that the CP content of wheat DDGS was between 30 and 48% and that the reported NDF content was between 29 and 57%. This variability is the result of a number of factors including the variety of wheat fermented, the ethanol plant producing the DDGS, and the temperature and length of the drying period (Nuez-Ortin, 2010). Table 2.2 shows a summary of the average nutrient composition of wheat and corn DDGS without debranning.

Table 2.2 Nutrient composition of wheat and corn DDGS

<i>Item (% dry matter basis)</i>	Wheat DDGS ^x	Corn DDGS ^y
Dry Matter	93.7	88.9
Crude Protein	39.2	30.2
Crude Fat	5.0	10.9
Neutral Detergent Fibre	48.1	42.1
Acid Detergent Fibre	11.0	16.2
Ash	5.1	5.8
Calcium	0.18	0.06
Phosphorus	0.91	0.89

Source:^x Nuez-Ortin and Yu (2009); ^ySpiehs et al. (2002)

The incorporation of debranning into the ethanol production process may influence the composition of the by-products as well. It is not known what the effects of debranning are on DDGS and other ethanol by-products as this has not been reported. However, the degree of debranning will significantly affect which layers of the kernel are removed and therefore what is being fermented and subsequently what is left behind as a by-product. Considering the chemical composition of a kernel of wheat, if the debranning process is successful at removing most of the bran and leaving the starchy endosperm intact, there are certain changes that would be expected to be seen in distiller's by-products such as wheat DDGS. Since the majority of the fibre in a wheat kernel is found in the bran, it is expected that if the bran is removed, the DDGS would be lower in both NDF and ADF which would cause a proportional increase in the protein content of the DDGS. Also, since the bran may contain up to 80% of the vitamins and minerals found in the wheat kernel, the DDGS would be lower in these constituents. This is potentially important, because DDGS is traditionally very high in phosphorus. This phosphorus may now be coming off in the wheat bran instead of carrying through to the DDGS. These changes in composition of wheat DDGS from plants that are debranning grain will change the feeding value of this by-product. If it is proven that debranning significantly reduces the fibre content of these by-

products, the use of DDGS in diets for monogastric animals may become feasible at higher levels than presently utilized.

2.4.2 Wheat Bran

The composition of wheat bran derived from the abrasion milling of wheat prior to ethanol production has not been studied. Most previous literature on the nutrient composition of wheat bran refers to bran derived from the flour milling industry. Production of bran from flour milling is a complex process. Wheat for flour production is cleaned and then tempered to aid in the separation of the starchy endosperm from other grain components (Pomeranz, 1987). The wheat is then put through a series of break rolls and sifters, each one finer than the previous to facilitate the removal of the bran and germ from the starchy endosperm. At the end of this process, white flour remains as the primary product (Pomeranz, 1987). This process is much more complex than production of bran from abrasion milling prior to ethanol production, which may or may not involve tempering and the wheat makes one pass through a chamber containing abrasive stones.

There will be similarities between this bran and the bran derived from ethanol production but the goals of flour milling and milling for ethanol production are different and the types of wheat commonly milled will be different. Bartnik and Jakubczyk (1989) reviewed the chemical composition of bran from the flour milling industry. They state that the composition of wheat bran is variable and depends on a large number of intrinsic factors related to the grain, including the variety and species of grain, kernel size and shape, and kernel maturity. It also depends on other factors such as grain storage, milling system used, length of time milled, and particle size. Although this review refers to flour production, bran from milling wheat for ethanol will also have varying quality depending on many of these same factors.

2.4.2.1 Crude Protein

The NRC (2000) states that the average CP value for wheat bran is $17.4 \pm 1.1\%$. This is based on an average of sixty-four samples and likely refers to samples from the flour milling industry. This protein value is approximately 3% higher than the CP content of the original grain ($14.2 \pm 2.0\%$) (NRC, 2000). This increase is due to the outer layers of the kernel being relatively rich in CP when compared to the starchy endosperm (Kent, 1966). Again, little data exists on the CP content of wheat bran derived from debranning for ethanol production, but it will most likely be lower in protein than the values from flour milling that have been reported in the literature. This is because ethanol plants are removing less of the kernel than in flour milling. As a result, the aleurone layer, which is high in protein, remains on the kernel rather than segregating with the bran. However, as with all other aspects of composition, the CP content of wheat bran is dependent on the quality of the original grain.

Wheat bran protein is reported to have a favourable amino acid profile (Bartnik and Jakubczyk 1989). When comparing the protein of the wheat bran to that of other sections of the kernel, the bran was about two times higher in alanine, arginine, asparagine, glycine and lysine (Hepburn et al. 1960; Miladi et al. 1972; Hansmeyer et al. 1976). This is significant, as lysine is often a limiting amino acid in diet formulation.

Table 2.3 Amino acid composition of the protein fraction of wheat bran^z	
Amino Acid	g/16 g N
Glutamate	18.42 ± 2.16
Aspartate	7.22 ± 0.61
Arginine	7.05 ± 0.46
Leucine	5.89 ± 0.33
Glycine	5.80 ± 0.59
Proline	5.71 ± 0.37
Alanine	5.26 ± 0.53
Valine	4.90 ± 0.18
Serine	4.37 ± 0.21
Lysine	3.99 ± 0.19
Phenylalanine	3.77 ± 0.16
Histidine	3.68 ± 0.43
Isoleucine	3.28 ± 0.01
Threonine	3.08 ± 0.22
Tyrosine	2.99 ± 0.14
Tryptophan	1.62 ± 0.28
Cystine	1.34 ± 0.16
Methionine	1.21 ± 0.23

^z16 grams of nitrogen represents approximately 100 g of crude protein

Adapted from Hepburn et al. (1960), Miladi et al. (1972) and Hansmeyer et al. (1976)

2.4.2.2 Fibre

Fibre is a major constituent of wheat bran. The NRC (2000) reports an average NDF content of $42.8 \pm 8.7\%$ and an ADF content of $14.0 \pm 1.5\%$. This constitutes 80% of the carbohydrates in the wheat bran (Schweizer and Wursch, 1979). Bartnik and Jakubczyk (1989) reported that bran is about 48% hemicellulose, 23% cellulose and 1.5% lignin (Bartnik and Jakubczyk 1989). Table 2.4 shows the amount of total fibre in the wheat kernel as well as where in the kernel this fibre is located. Again, the fibre profile of the wheat kernel will depend on many factors including variety of wheat and growing conditions. The results of Bartnik and Jakubczyk (1989) clearly show that the high fibre content of wheat bran is due to the pericarp layer of the kernel. This is true of wheat bran derived from flour milling and also for that from

the ethanol industry. If only a small portion of the kernel is removed, the bran will consist entirely of the pericarp layer.

Table 2.4 Distribution and composition of fibre in a kernel of wheat

Part of Grain	% of Kernel	Total Fibre	Hemicellulose	Cellulose	Lignin
Whole Grain	100	8.6	4.2	3.1	1.3
Pericarp	3.3	73.0	48.1	23.4	1.5
Aleurone Layer and testa	18.3	23.0	9.8	7.7	5.4
Endosperm	76.0	2.3	0.9	1.1	0.3
Germ	2.4	9.6	3.6	4.8	1.1

Adapted from Bartnik and Jakubczyk (1989).

2.4.2.3 Vitamins and Minerals

Wheat bran is known to be high in many vitamins and minerals. This is because 80% of the total mineral content of the wheat kernel is located in the pericarp and aleurone layers, with the remaining 20% in the starchy endosperm (Bartnik and Jakubczyk 1989). Czerniejewski et al. (1964) found that bran from hard wheat had on average fifteen times more ash than the flour from the same wheat. The same study found that minerals that were particularly concentrated in the bran included calcium, copper, sodium, molybdenum, potassium, phosphorus, zinc, manganese, iron, magnesium and cobalt (Table 2.5) . These minerals were anywhere from 10 to 27 times more concentrated in the bran than in the flour. It is difficult to give exact values for each mineral in wheat bran as this varies due to grain variety, growing conditions and system of grain milling.

Table 2. 5 Mineral Content of Wheat Bran (Mean \pm SD)	
Potassium (mg/100 g) ^{x,y,z}	1242 \pm 372
Phosphorus (mg/100 g) ^{x,y,z}	1078 \pm 457
Magnesium (mg/100 g) ^{x,y,z}	508 \pm 167
Calcium (mg/100 g) ^{x,y,z}	99 \pm 28
Sodium (mg/100 g) ^{x,y}	19 \pm 17
Zinc (ppm) ^{x,y,z}	59 \pm 44
Iron (ppm) ^{x,y,z}	82 \pm 66
Manganese (ppm) ^{x,y,z}	93 \pm 66
Copper (ppm) ^{x,y,z}	9 \pm 7
Molybdenum (ppm) ^x	0.80
Cobalt (ppm) ^x	0.11

Adapted from: ^xCzerniejewski et al. (1964); ^yFellers et al. (1968); ^zPeterson et al. (1983)

Wheat bran is also considered to be a rich source of vitamins, particularly those in the vitamin B complex (Calhoun et al. 1960; Farajzadeh and Monji, 2004). Depending on factors such as variety, milling and growing conditions, 50 to 90% of the vitamins in the whole kernel can be found in the bran (Table 2.6) (Calhoun et al. 1960; Bartnik and Jakubczyk, 1989). This is of particular interest when incorporating wheat bran into diets for people and for monogastric animals.

Table 2.6 Vitamin content of wheat bran versus that of flour		
Vitamin	Bran ($\mu\text{g g}^{-1}$)	Flour ($\mu\text{g g}^{-1}$)
Thiamine	6.29	0.76
Riboflavin	3.34	0.32
Niacin	266.0	10.1
Pantothenic Acid	39.10	4.83
Folic Acid	0.88	0.11
Biotin	0.44	0.014

Adapted from: Calhoun et al. (1960)

2.4.2.4 Anti-nutritional Factors

2.4.2.4.1 Phytates and Phenolic Compounds

Wheat bran also contains several compounds which are referred to as anti-nutritional factors, particularly with respect to humans or monogastric animals. One of these compounds is phytate or phytic acid. Studies have shown that phytic acid is mostly concentrated in the outer layers of the wheat kernel (Williams, 1970). To illustrate this, Bartnik and Jakubczyk (1989) state that white flour contains 98 to 124 mg/100 g of phytic phosphorus, while wheat bran contains 760 to 804 mg/100 g phytic phosphorus. Phytic acid was considered to be an anti-nutritional factor as it binds with minerals to form insoluble compounds which cannot be absorbed from the intestine (O'Dell and de Bolland, 1976). In animal nutrition, particularly in monogastric nutrition, phytic acid has been studied in depth because many plant-based diets contain substantial amounts of phytic acid. Phytic acid has been shown to inhibit the absorption of minerals such as calcium, zinc and phosphorus (Lonnerdal et al. 1988; Torre et al. 1991). When monogastric diets are high in phytic acid, the enzyme phytase is often fed to break release phosphorus associated with phytic acid, and prevent it from forming insoluble compounds with minerals (Cowieson et al. 2004; Knowlton et al. 2007). In a study with broiler chickens that had phytic acid added to their diets, it was found that supplementing with phytase reduced excretion of endogenously produced amino acids, iron, sodium, sulphur and phosphorus (Cowieson et al. 2004). Supplementing with phytase is more common in monogastric than in ruminant diets because bacteria in the rumen produce phytase which helps to break down phytate phosphorus (Knowlton et al. 2007)

The binding of nutrients by phytic acid can be an environmental issue (Erickson et al. 1998). In animal feeding, this binding often causes excess secretion of phosphorus in the manure

(Erickson et al. 1998). This leads to a need for increased land for manure spreading in order to keep nutrient ratios correct from a plant utilization perspective (Erickson et al. 1998). In consideration of these problems, there has been some research done on developing a variety of wheat that is lower in phytic acid (Guttieri et al. 2004).

Although phytic acid has been implicated in binding and inhibiting absorption of important minerals, recent research has shown that phytic acid can have positive effects on human health. A study done by Jenab and Thompson (2000) showed that when wheat bran was added to a low fibre diet consumed by humans, cell growth, differentiation and colon health were positively affected. These researchers hypothesized that the reason for this was a combination of the high dietary fibre and phytic acid content of wheat bran. Graf and Eaton (1993) proposed that phytic acid helps protect against colon cancer by preventing proliferation of bacteria that produce free radicals that damage intestinal cells. These potential human health benefits from the combination of dietary fibre and phytic acid found in wheat bran may outweigh the above described disadvantages with respect to mineral availability. It also illustrates that while low phytic acid wheat may be beneficial for the agriculture industry, for human use it may not be necessary or desirable.

Wheat bran also contains phenolic compounds, such as alkylresorcinols and tannins which are considered to be anti-nutritional factors in livestock feeding. Alkylresorcinols are phenolic lipids which have been shown to reduce growth rate and intake by binding protein and making it unavailable (Wieringa, 1967). Tannins are bitter tasting poly-phenolic compounds that bind protein similarly to alkylresorcinols (Wieringa, 1967). These phenolic compounds have been shown to reduce dry matter intake and thereby negatively impact growth rate (Kozubek, 1999). Although these compounds are considered to be a negative component of livestock diets,

similar to phytic acid, they have beneficial effects on human health (Kozubeck, 1999). Alkylresorcinols have been reported to have antimicrobial, antiparasitic, antitumour and antioxidative effects in human medicine. It has been shown that alkylresorcinols are toxic to several pathogenic gram-positive bacteria, for example *Mycobacterium tuberculosis* (Kozubeck, 1999).

2.4.2.4.2 Environmental Contaminants

Wheat bran, which comprises of the outermost layers of the wheat kernel, is subject to environmental contamination (Bartnik and Jakubczyk, 1989). Contaminants from herbicide and pesticide residues, as well as mycotoxins such as aflatoxin, may be present on the surface of grain (Bartnik and Jakubczyk, 1989). In a study by Tamba-Berehoiu (2010) it was shown that aflatoxin was four times more concentrated in wheat bran than in the original wheat grain. Bartnik and Jakubczyk (1989) stated that while washing or cleaning of grain prior to milling will help to eliminate some of these contaminants, it is difficult to remove them completely.

2.5 Use of Wheat Bran as a Feed

2.5.1 Use of Wheat Bran in Diets for Monogastric Animals

The high fibre content of wheat bran makes it less desirable for monogastric animals than for ruminants, as monogastrics are unable to digest a large portion of this fibre. Furthermore, many of the nutrients present in bran, including protein and many vitamins and minerals, are within the cells of the aleurone layer. These cells have thick cell walls consisting of hemicellulose and cellulose (Bartnik and Jakubczyk, 1989). Monogastric animals cannot efficiently break down these fibrous cell walls and are unable to access these nutrients. There

have been several studies done in which feeding wheat bran to pigs was studied. Kyriazakis and Emmans (1995) studied the effects on intake of pigs when a nutrient dense diet was diluted with wheat bran at 25, 50, 75 and 100%. They found that at 25 and 50% inclusion, DM intake increased but as wheat bran inclusion level was increased to 75 and 100%, DM intake was decreased. They attributed this decrease in intake to an increase in gut fill of the pigs (Kyriazakis and Emmans, 1995).

Although the effects of wheat bran on diet digestibility and intake of monogastric animals may not be positive, wheat bran has potential as a health promoting material. A study in weaned pigs showed that supplementation with wheat bran led to a reduction in the amount of pathogenic *E. coli* excreted in the feces as well as a reduction in diarrhea after weaning (Molist et al. 2010). Another study in pigs found that wheat bran could help to mitigate colon cancer (Govers et al. 1999). It was found that when wheat bran was fed along with a resistant starch, that starch fermentation was shifted from the caecum to the proximal colon (Govers et al. 1999). This decreases ammonia concentration and thereby improves the conditions in the lumen of the distal colon. The distal colon is the area where most colon cancer occurs and improving the conditions there can lead to decreased tumour formation (Govers et al. 1999).

2.5.2 Use of Wheat Bran in Diets for Ruminants

2.5.2.1 Comparison of Wheat Bran to Barley or Corn Grain as an Energy Source for Ruminants

Although wheat bran from flour milling and from ethanol pre-processing are different, existing data on the feeding value of wheat bran from flour milling is useful to help predict animal performance from bran from ethanol pre-processing. Two studies in small ruminants (;

Singh et al. 1999; Dhakad et al. 2002) found that wheat bran can replace barley or corn grain. Dhakad et al. (2002) found that up to half of the concentrate fed to lambs could be replaced with wheat bran without any adverse effect on performance. Singh et al. (1999) found similar results and concluded that up to 50% of rolled barley grain could be replaced with wheat bran in diets for adult sheep without affecting intake or performance.

However, not all studies using wheat bran as a replacement for grain are in agreement. In a study in calves that were grazing fescue pasture, Hess et al. (1996) found that calves supplemented with wheat bran gained less than calves supplemented with corn grain. However, wheat bran feeding did not have any adverse effects on intake (Hess et al. 1996). Although literature is not in complete agreement on the effects of wheat bran on animal performance, it does show that depending on animal performance goals, wheat bran may be a cost effective replacement for up to 50% of barley or corn grain in ruminant diets.

2.6 Effect of Wheat Bran on Diet Digestibility and Parameters of Rumen Fermentation

2.6.1 Digestibility of Wheat Bran

Wheat bran is lower in starch and higher in fibre and ash than traditional concentrate sources used in ruminant feeding. Although there are not many studies on the digestibility of wheat bran, research is in agreement that dry matter digestibility tends to decrease as wheat bran replaces grain. One study on adult sheep reports that when 50% of rolled barley was replaced with wheat bran, DM, organic matter (OM), nitrogen free extract and total carbohydrate digestibility were unaffected (Singh et al. 1999). However, when wheat bran completely replaced rolled barley, digestion of the above nutrients was significantly decreased (Singh et al. 1999).

2.6.2 Volatile Fatty Acids

Rumen fermentation, including the production of volatile fatty acids (VFAs), is cyclical in nature and depends upon the feedstuffs the animal is consuming (Shaw et al. 1960; Van Soest, 1994). The three main VFAs produced by fermentation in the rumen are acetate, propionate and butyrate (Van Soest, 1994). The amount and ratios of VFAs in the rumen are impacted by the type of carbohydrate consumed (Bergman, 1990). This is because carbohydrates are the major source of energy for the rumen microbes (Bergman, 1990). Although carbohydrates are very important, other compounds such as protein and some short chain lipids can also be fermented (France and Dijkstra, 2005). Branched chain fatty acids, including isovaleric and isobutyric acid can also be formed in the rumen from fermentation of rumen degradable protein (France and Dijkstra, 2005).

The type of feedstuff consumed influences how much of each VFA is produced. Diets which are high in forage have lower total production of VFAs and higher acetate to propionate ratios (van Houtert, 1993). Wheat bran is high in fibre when compared to grains such as corn and wheat. Although limited data exists on the effects of wheat bran on production of VFAs, a study by Hess et al. (1996) found that steers grazing pasture with no supplementation had the highest concentration of acetate and that steers consuming 0.48% of body weight as wheat bran had higher acetate than steers consuming 0.34% of body weight as wheat bran. This study also found that there was no difference between the control and wheat bran diets on the total amount of VFAs produced in the rumen.

2.6.3 Rumen Ammonia-N

Within the rumen, rumen degradable protein is broken down by specific anaerobic bacteria and rumen ammonia nitrogen ($\text{NH}_3\text{-N}$) is produced (Huntington and Archibeque, 1999). The rumen $\text{NH}_3\text{-N}$ is formed when protein is broken down by microbes and amino acids are deaminated (Huntington and Archibeque, 1999). Ammonia released is then used by other rumen bacteria to produce microbial protein (Huntington and Archibeque, 1999). Cellulolytic bacteria in particular rely on rumen $\text{NH}_3\text{-N}$ to synthesize protein (Russell et al. 1992; Huntington and Archibeque, 1999). Measurement of $\text{NH}_3\text{-N}$ in the rumen can help to explain how feed is being degraded and utilized in the rumen. When rumen $\text{NH}_3\text{-N}$ values are very low it can mean that energy and nitrogen fermentation is being synchronized efficiently in the rumen (Olson et al. 1999). However, it can also indicate that the dietary nitrogen source being provided is less degradable and thus less $\text{NH}_3\text{-N}$ is being released (Rodriguez et al. 1997). A high concentration of rumen $\text{NH}_3\text{-N}$ could indicate that the dietary nitrogen source is rapidly degradable or that energy and nitrogen fermentation are not synchronized causing excess $\text{NH}_3\text{-N}$ to accumulate (Huntington and Archibeque, 1999).

Again, very little data exists on the effects of feeding wheat bran on rumen $\text{NH}_3\text{-N}$ concentration. Hess et al. (1996) found that steers on pasture supplemented with wheat bran had higher rumen $\text{NH}_3\text{-N}$ concentrations than steers that were supplemented with corn or those that were not supplemented at all. As indicated above, this increase in rumen $\text{NH}_3\text{-N}$ in wheat bran diets could be due to the fact that fermentation of energy and nitrogen were not synchronized.

2.6.4 Rumen Passage Rate

According to van Soest (1994) rate of passage is the flow of solid and fluid residues out of the rumen. Rumen passage rate can be broken up into two parts, passage rate of the solid and fluid phases. Passage rate is often measured by using an indigestible marker that is consumed with the feed and remains associated with the particular phase one is measuring. The marker travels through the digestive system with that phase (van Soest, 1994). Another way of measuring passage rate from the rumen is to administer a pulse dose of a marker directly into the rumen (Van Soest, 1994). After a pulse dose is administered, collections are taken frequently over a period of hours or days. With this technique, after the marker first appears, it rises to its maximum concentration followed by an asymptotic decline in the concentration of the marker. (Van Soest, 1994).

Rate of passage can greatly affect animal performance. Slower rates of passage lead to less dry matter intake (DMI) due to gut fill and rumen distension (Robles et al. 1981). However, if passage rate becomes too fast, feed residues leaving the rumen may not be completely digested (Robles et al. 1981; Firkins et al. 1998). This can lead to decreased microbial protein production (Firkins et al. 1998). However, faster passage rate will also increase DMI which may allow the animal to absorb the same amount or more nutrients in total (Musimba et al. 1987). Generally, increased forage intake is associated with slower rates of passage. In regards to the effects of wheat bran on passage rate, little research exists. Hess et al. (1996) found no difference in fluid or particulate passage when grazing steers were supplemented with wheat bran or corn grain. Although wheat bran is very high in fibre, its small particle size may cause it to have different effects on passage rate than more traditional forage sources.

2.7 Use of Wheat Bran in Combination with Other By-product Feeds

2.7.1 Condensed Liquid Whey (Whey Permeate)

Whey permeate or condensed liquid whey (CLW) is a by-product of cheese processing that has had the fat separated from it before processing as well the majority of the protein fraction removed by ultrafiltration (Mason et al. 2007). Whey has in the past been disposed of as a waste product (Lynch and McDonough, 1979). However, whey retains about 55% of the nutrients found in the original milk. This makes whey a potentially valuable by-product feed. There are several different types of whey that may be fed as an animal feed. Most of the research has been done on CLW, acid liquid whey, and sweet liquid whey. Acid liquid whey and sweet liquid whey are higher in moisture than CLW. These products are approximately 6-7% dry matter, whereas CLW is upwards of 20% dry matter (Modler, 1987). Although liquid whey is nutritious, the nutrients are diluted by its high moisture content (Juengst, 1978). According to the nutrient composition of whey permeate, sweet whey and acid whey presented by Modler (1987) as well as current analysis of CLW supplied by Saputo, condensed liquid whey is higher in lactose and protein than other types of liquid whey.

A study by Schingoethe (1975) states that ruminants can consume up to 30% of their total DMI as liquid whey. At levels higher than 30%, liquid whey intake will begin to limit DMI because of gut fill (Schingoethe et al. 1980). This leads to a decrease in animal performance. However, since CLW is more nutrient dense, higher percentages may be able to be fed before gut fill becomes a factor.

The protein found in whey is of very high quality (Schingoethe, 1975). It has a high protein efficiency ratio of 3.0 to 3.2 (Schingoethe, 1975). Dried whey has an energy value comparable to corn (Schingoethe, 1975). Schingoethe (1975) stated that 40% of calcium and

43% of phosphorus from the original milk can be found in the whey. It has been found that rumen butyrate and propionate levels are increased when whey is fed (Schingoethe, 1975; Schingoethe et al. 1980; DeFrain et al. 2004). These researchers hypothesized that the rapid digestion of lactose is leading to this increase. Since lactose concentrations are higher in condensed whey than in other whey products, CLW feeding leads to higher levels of butyrate and propionate (Susmel et al. 1995). This increase in butyrate production can have potential health benefits and possibly boost immune response (Weber and Kerr, 2006). However, urine volume is also increased when liquid whey is fed (Schingoethe et al. 1980; Susmel et al. 1995). Schingoethe et al. (1980) found that urine output was increased by up to 300% when liquid whey was included in the diet. This increased urine output was most likely due to increased sodium content in diets containing liquid whey. This could have potentially harmful effects on animal health as well as environmental concerns.

Liquid whey inclusion can also have a negative effect on fibre digestibility because it increases passage rate (Rogers et al. 1977). However, studies disagree about the affects of whey on fibre digestion in the rumen. A study by Huhtanen et al. (1954) showed that digestion of fibre in an artificial rumen was lowered when lactose was included in the diet. However, Modler (1987) stated that cattle consuming a diet containing whey had superior fibre degradation than those consuming no whey. Feeding whey also affects rumen pH (Susmel et al. 1995). It was found that steers fed whey had a lower pH 1.5 and 3 hours after feeding; however 4.5 hours after feeding, rumen pH was the same as in those on diets containing no whey (Susmel et al. 1995). To date, no studies have looked at the possibly of combining the feeding of CLW with wheat bran although Mason et al. (2007) states that feeding CLW can enhance intake and utilization of low quality by-product feeds.

2.8 Summary

As use of ethanol in fuel continues to increase, the demand for grain will continue to increase as well. High grain prices and social pressures such as the food vs. fuel debate will cause feeding of lower quality by-product feeds to become increasingly common. Existing ethanol plants will also be affected by higher grain prices and will be focused on maximizing production. Installation of front end debranning equipment into ethanol plants will become more common as producers try to maximize starch throughput and ethanol production without expanding plant size. This will lead to an increased volume of wheat bran being generated by the ethanol industry. The literature shows that at least 50% of grain can be replaced with wheat bran derived from the flour milling industry. However, no data exists on the composition and feeding value of wheat bran derived from abrasion milling prior to ethanol production.

While the composition of wheat bran produced by abrasion milling prior to ethanol production is not known, its composition is likely to be similar to that of wheat bran from flour milling, with a few key differences. The reported CP content of wheat bran from the NRC (2000) is $17.4 \pm 1.1\%$, this is higher than preliminary CP analysis of wheat bran from the ethanol industry. This is likely because flour milling removes more of the kernel including the aleurone layer which is very high in protein (Bartnik and Jakubczyk, 1989). The aleurone layer is likely not removed when wheat is debranned prior to ethanol production. Similarly, wheat bran from flour milling is most likely higher in fat than wheat bran from ethanol abrasion milling as it is likely that flour milling removes more of the germ. Neutral detergent fibre and ADF content of wheat bran as reported by NRC (2000) are $42.8 \pm 8.7\%$ and $14.0 \pm 1.5\%$ which according to preliminary analysis is similar to wheat bran from ethanol

production. Limited data on cattle performance and rumen fermentation parameters on wheat bran produced from flour milling indicates that it is less digestible than corn or barley grain (Singh et al. 1999). No significant effects of wheat bran on passage rate or volatile fatty acid content have been found, but one study by Hess et al. (1996) showed that wheat bran as a supplement for calves on pasture produced higher rumen ammonia-N levels. This gap in information on wheat bran produced from abrasion milling prior to ethanol production must be filled so that when this by-product becomes more available, producers can decide if it is a viable feedstuff for their management system. It is also of interest to explore the potential interaction between wheat bran and CLW on performance and rumen fermentation parameters.

The hypothesis of the research conducted for this thesis was that due to its high digestible NDF content and moderate starch and protein content that wheat bran from abrasion milling prior to ethanol production would be able to replace barley grain in diets for backgrounding calves with no adverse effects on performance or rumen fermentation. The objectives of the studies that follow were to evaluate wheat bran as replacement for barley grain with respect to: 1) animal performance, 2) ultrasound carcass traits, 3) diet digestibility and dry matter intake and 4) rumen fermentation parameters.

3.0 EFFECT OF WHEAT BRAN AND CONDENSED LIQUID WHEY ON PERFORMANCE OF BACKGROUNDING CALVES

3.1 Introduction

Replacement of traditional high energy feeds such as corn and barley grain with by-product feeds is becoming increasingly common. Use of these feeds allows producers to reduce the cost of feeding cattle. Wheat bran derived from abrasion milling prior to ethanol production is a new by-product feed that has not been previously fed to livestock. In regards to cattle and other ruminants, existing data is based on wheat bran from flour milling. The NRC (2000) states that wheat bran from flour milling contains 17% crude protein, 4.3% crude fat, 42.8% NDF and 14.0% ADF. The NRC (2000) values for NE_m and NE_g for wheat bran are 1.63 and 1.03 Mcal/kg (DM), respectively. The major type of fibre found in wheat bran is hemicellulose (Bartnik and Jacubczyk, 1989), which is very digestible by ruminant animals. Previous literature on wheat bran from flour milling is inconsistent in terms of animal performance. Two studies in sheep showed that wheat bran could replace up to half of barley or corn grain without any adverse effects on performance (Singh et al. 1999; Dhakad et al. 2002). In contrast, Hess et al. (1996) reported that wheat bran was unable to sustain the same gains as corn grain when used as a supplement for calves grazing fescue pasture.

Another example of a by-product used in cattle feeding is CLW which is derived from the milk processing industry. Condensed liquid whey is about 20% dry matter, 81% lactose, 3.4% protein and 8.7% ash (Modler, 1987; Mason et al. 2007). These materials are very readily digested by both monogastric and ruminant animals. In ruminants, lactose is hydrolyzed to glucose and galactose which are then fermented to VFAs (Weisbjerg et al. 1998). However,

lactose is not degraded as quickly as other sugars such as sucrose. As such, it does not cause the same rapid drop in pH that other sugars do (Weisbjerg et al. 1998). One study reported that CLW can be included in diets at levels up to 30% of total diet DM in lactating dairy cows (Schingoethe et al. 1980). However, Mason et al. (2007) stated that CLW or whey permeate can be fed at levels of about 3 to 5% of total dry matter intake. Feeding of whey has also been shown to improve palatability and reduce sorting behavior (Mason et al. 2007). Along with this, it has been shown that inclusion of whey seems to increase intake and utilization of low quality by-products (Mason et al. 2007). Although this literature is a useful starting point, it is important that we understand the chemical composition of wheat bran from ethanol pre-processing and its value as a feed source for growing cattle when fed alone or in combination with other by-products such as CLW.

The nutritional characteristics of wheat bran (high digestible fibre and moderate starch and protein) along with those of CLW (rapidly degradable carbohydrate) led to the hypothesis that feeding these two by-products concurrently may benefit rumen fermentation and thereby benefit animal performance. This potential synergy between wheat bran and CLW would allow the replacement of barley grain in part or in whole, with two lower cost by-product feeds.

The objectives of this trial were to compare the performance of calves fed traditional barley based backgrounding diets to calves fed wheat bran and/or CLW as a partial replacement for barley grain, specifically to determine if wheat bran and/or CLW are a suitable replacement for barley grain by measuring a) performance (average daily gain, feed intake and feed efficiency) and b) ultrasound live animal carcass traits (*l. dorsi* area and subcutaneous backfat).

3.2 Materials and Methods

3.2.1 Experimental Design, Animals and Housing

All cattle used in this study were cared for in accordance with the guidelines of the Canadian Council on Animal Care (CCAC, 1993). Three hundred and twelve Angus cross steers (303 kg \pm 65 kg) were purchased from local auction markets and shipped to the University of Saskatchewan's Beef Cattle Research Station (BCRS) where they were tagged and vaccinated with UltraBac 7/Somnubac (Pfizer Animal Health, New York, NY, United States of America), Bovashield Gold 5 (Pfizer Animal Health), and long acting Liqueamycin (Pfizer Animal Health, New York, NY). Steers were also treated for both external and internal parasites with IvomecTM (Merial Canada Inc., Baie d'Urfe, QC, Canada). All steers were fed a common receiving diet containing, on a DM basis, 26.7% barley silage, 29.3% grass hay, 29.1% rolled barley, 7.5% wheat/corn blend DDGS and 7.4% supplement from arrival until the beginning of trial. The trial was designed as a completely randomized design with a 2x3 factorial arrangement of treatments. At the start of the trial, steers were weighed on two consecutive days and randomly assigned to one of twenty-four pens. Each pen was randomly assigned to one of the six treatments. The trial was designed to background calves at a targeted weight gain of 1.1 kg d⁻¹ and a targeted end weight of 430 kg.

3.2.2 Treatments and Diet Composition

At the beginning of the trial, steers were switched directly onto their experimental diets without adaptation as the experimental diets were very similar in energy to the receiving diet. A 2x3 factorial design of treatments was used with two levels of CLW (0 and 4.6% on a DM basis) and three levels of wheat bran (0, 14 and 28% on a DM basis). The control diets were

formulated, to contain 13.3% barley silage, 40.8% alfalfa/brome grass hay, 31.8% barley grain, 7.2% wheat/corn blend DDGS and 6.9% supplement (DM basis). The 0% whey diet was identical to the control except 4.6% (DM basis) of the rolled barley was replaced with CLW. The four remaining treatments replaced barley grain with wheat bran at 14 and 28% of the diet on a (DM basis) (Table 3.2). In diets that did not contain CLW, water was added to equilibrate the moisture content between treatments. Diets were formulated to 14.0% CP, 1.55 and 0.95 Mcal kg⁻¹ NEm and NEg, respectively, in order to meet the requirements for 1.1 kg d⁻¹ gain for 300 kg calves as outlined by NRC (2000) (Table 3.1).

Wheat bran was obtained from Pound-Maker Agventures and stored outdoors under a covered roof. Condensed liquid whey was obtained from Saputo (Saskatoon, SK.) and stored indoors in a plastic tank. The barley grain fed was purchased from commercial sources (62.5 kg hL⁻¹) and was dry rolled to a processing index of 76.1% at the Beef Cattle Research Centre at the University of Saskatchewan (RossKamp Champion, Waterloo, IA). Processing index was calculated as the volume weight of processed barley expressed as a percent of the weight of the same volume of unprocessed barley (Beauchemin et al. 2001). The DDGS was from Husky Energy (Lloydminster, SK.) and was a 50:50 wheat/corn blend DDGS. Barley silage (AC Rosser) was grown at the University of Saskatchewan farm and stored in a bunker silo. Brome grass/alfalfa hay was grown at the University of Saskatchewan and ground in a tub grinder (Haybuster H-1000, DuraTech Industries International, Jamestown, ND.) through a 9.5 cm screen.

Samples of barley silage were taken every two weeks for measurement of DM content. Representative samples of barley, supplement, DDGS and wheat bran were taken from each load. Hay was ground every two weeks with a tub grinder and samples were taken every time

new hay was ground. Bunk samples of total mixed ration were taken from every pen every two weeks and compiled by treatment.

Table 3.1 NRC Requirements of 300 kg steers as compared to the formulated composition of the control diet (NRC. 2000) for a target gain of 1.1 kg d⁻¹

	NRC Recommended Values	Formulated Composition of the Control Diet
CP (%DM)	11.6	14.0
NE _m (Mcal kg ⁻¹)	1.52	1.55
NE _g (Mcal kg ⁻¹)	0.92	0.95

3.2.3 Collection of Animal Performance Data

Animals were fed *ad libitum* once daily in the morning. The amount of feed provided to each pen was recorded daily. Bunks were cleaned every two weeks and orts were weighed and discarded. Dry matter intake was calculated for each pen based on the amount of feed (DM basis) and adjusted for orts. Net energy of gain of the control and experimental rations was calculated from animal performance as described by Zinn and Shen (1998) and outlined by McKinnon and Walker (2008).

Ultrasound *longissimus dorsi* area (USLA) as well as ultrasound subcutaneous fat (USFAT) thickness were measured at the beginning, middle and end of the trial using an Aloka 500 V real-time ultrasound machine and a 17-cm linear array transducer according to the procedure outlined by Bergen et al. (1997).

3.2.4 Chemical Analysis

All feed and bunk samples were dried in an oven with forced air flow at 55 °C for 72 hours. Samples were ground using a lab-scale hammer mill fitted with a 1 mm screen (Christy

and Norris 8" lab mill, Christy Turner Ltd. Chelmsford, UK). Bunk samples of total mixed ration were analyzed in duplicate for dry matter (AOAC method 930.15), crude protein using a nitrogen conversion factor of 6.25 (AOAC method 984.13), neutral detergent fibre with sodium sulphite and alpha amylase (AOAC method 2002.04), acid detergent fibre (AOAC method 973.18), calcium (AOAC method 927.02) and phosphorus (AOAC method 965.17).

3.2.5 Statistical Analysis

Data was analyzed using the mixed model procedure of SAS as a completely randomized design with a 2x3 factorial arrangement of treatments with pen as the experimental unit (N=4) and the fixed effect of treatment (SAS Version 9.2; SAS Institute, Inc., Cary, NC.). Satterthwaite's method was used to approximate degrees of freedom and a Kenward Roger adjustment was used to adjust standard errors. Differences were considered significant if $P < 0.05$. Means were separated using Tukey's HSD (honestly significant difference) method of comparing means. Trends were discussed at $P < 0.10$.

Table 3.2 Ingredient composition, supplements and total mixed diets containing 0, 14, or 28% wheat bran with or without the inclusion of condensed liquid whey

	Treatment					
	Control	No CLW 14% WB	28% WB	Control	CLW 14% WB	28% WB
<i>Diet Composition (%DM basis)</i>						
Barley Silage	13.3	13.3	13.3	13.3	13.3	13.3
Grass Hay	40.8	40.7	40.6	40.7	40.6	40.6
Barley Grain	31.8	18.1	4.5	27.2	13.6	0.0
Wheat/Corn Blend DDGS	7.2	7.2	7.2	7.3	7.3	7.2
Wheat Bran	0.0	13.8	27.4	0.0	13.7	27.4
Condensed Liquid Whey	0.0	0.0	0.0	4.6	4.6	4.6
Supplement	6.9	6.9	7.0	6.9	6.9	6.9
<i>Supplement Composition (%DM basis)</i>						
Barley	71.5	64.5	58.0	71.5	64.5	58.0
Limestone	5.0	12.0	18.5	5.0	12.0	18.5
Vitamin Premix ^x	9.0	9.0	9.0	9.0	9.0	9.0
Ionophore Premix ^y	7.0	7.0	7.0	7.0	7.0	7.0
Trace Mineral Salt ^z	4.5	4.5	4.5	4.5	4.5	4.5
Canola Oil	3.0	3.0	3.0	3.0	3.0	3.0

^xUniversity of Saskatchewan vitamin A & D supplement = 440,500 IU vitamin A, and 88,000 IU vitamin D3 kg⁻¹

^yUniversity of Saskatchewan Feed Unit Ionophore Premix: contains 96.77 % barley and 3.23 % Rumensin®

Premix containing monensin (as monensin sodium) at 200 g kg⁻¹ (Elanco, Guelph, ON) (DM basis)

^zTrace mineral salt: 95 % NaCl, 12, 000 ppm Zn, 10, 000 ppm Mn, 4000 ppm Cu, 400 ppm I, 60 ppm Co, 30 ppm Se

3.3 Results and Discussion

3.3.1 Diet Composition and Analysis

The CP content of wheat bran throughout the trial averaged 11.45% (Table 3.3), which is lower than values reported in literature as well as by the NRC (2000) for wheat bran from flour milling (Bartnik and Jakubczyk, 1989; Dhakad et al. 2002; NRC, 2000). The NDF and ADF content of the wheat bran were 41.7 ± 4.0 and $15.8 \pm 1.5\%$ respectively, which is similar to values reported by (NRC, 2000). Table 3.3 shows the average composition of the barley grain, wheat bran and CLW fed throughout the present trial and illustrates that wheat bran is marginally higher in crude fat (ether extract) and 20% lower in starch than barley grain.

Table 3. 3 Chemical composition (%DM basis) of wheat bran, barley grain and condensed liquid whey used in backgrounding trial

	Wheat Bran (N=3)	Barley Grain (N=2)	Condensed liquid whey (N=4)
<i>Chemical Composition (% DM basis)</i>			
	Mean \pm SE	Mean \pm SE	Mean \pm SE
Dry Matter	91.2 \pm 0.78	89.5 \pm 0.69	19.3 \pm 0.81
Crude Protein	11.5 \pm 0.21	13.3 \pm 0.57	3.6 \pm 0.13
Neutral Detergent Fibre	41.7 \pm 4.03	19.1 \pm 0.42	-
Acid Detergent Fibre	15.8 \pm 1.48	7.4 \pm 1.56	-
Ether Extract	2.8 \pm 0.07	1.8 \pm 0.35	0.8 \pm 0.11
Ash	-	-	8.5 \pm 0.46
Starch	33.9 \pm 1.27	58.5 \pm 1.80	-
Lactose ^z	-	-	87.1 \pm 0.95

^zlactose determined by difference

Analysis of total mixed rations fed during the backgrounding trial (Table 3.4) showed that CP levels for all diets exceeded the NRC (2000) requirements set for calves of this weight. Crude protein was higher ($P < 0.05$) in the diets that did not contain CLW (Table 3.5). This is expected as barley grain is higher in protein than CLW. As expected, NDF content increased ($P < 0.01$) and ADF content tended to increase ($P = 0.07$) in rations as wheat bran was added to

diets. Acid detergent fibre tended to decrease ($P=0.09$) when CLW was added to diets. These results were expected as wheat bran is lower in starch and higher in structural carbohydrates than barley grain and barley grain is higher in structural carbohydrates than CLW. Ash also increased ($P<0.05$) as wheat bran was added, most likely due to the high mineral content in the bran. This increase in fibre as well as ash agrees with previous literature on replacement of grain with wheat bran or other high fibre by-products (Garg et al. 1986; Malik et al. 1989; Singh et al. 1999).

Table 3.4 Comparison of crude protein, neutral detergent fibre, acid detergent fibre and ash content of backgrounding rations containing wheat bran (WB) and or liquid whey (CLW)

	Dietary Treatment									
	Wheat Bran					CLW				
	Control	14% WB	28% WB	SEM	P-value	Control	4.6% CLW	SEM	P-value	
Ration Analysis (%DM basis)										
Crude Protein	13.83	14.07	13.79	0.148	0.36	14.09	13.71	0.121	0.04	
Neutral Detergent Fibre	42.72	45.33	47.53	0.633	<0.0001	45.15	45.23	0.517	0.91	
Acid Detergent Fibre	25.72	26.57	27.19	0.428	0.07	26.93	26.06	0.349	0.09	
Ash	6.09	6.90	7.07	0.115	<0.0001	6.60	6.78	0.094	0.19	

No significant wheat bran x condensed liquid whey interaction was seen for any parameters

3.3.2 Backgrounding Performance

The effects of replacing barley grain with wheat bran and/or condensed liquid whey are shown in Table 3.5. There were no wheat bran x condensed liquid whey interactions ($P > 0.05$) were detected. The inclusion of condensed liquid whey had no effect ($P > 0.05$) on any of the measured performance parameters. The replacement of barley grain with wheat bran at 14 or 28% of the diet dry matter had no effect ($P > 0.05$) on average daily gain. However, feed intake was increased by 9 and 11% ($P < 0.05$) when wheat bran was included in diets at 14 and 28% of DM, respectively. As a result of this increase in feed intake, feed:gain was increased ($P < 0.05$) by 10 and 15% at the 14 and 28% inclusion levels, respectively. Calculated net energy of gain based on animal performance was reduced by 8 and 13% ($P < 0.05$) in diets containing either 14 or 28% wheat bran, respectively. Dhakad et al. (2002) reported similar results in that lambs fed wheat bran at 17 or 30% of total diet dry matter as a replacement for corn grain had similar weight gains to one another; however, lambs fed 51% wheat bran had reduced gains. Unlike in the present trial, these authors found no difference in feed efficiency or dry matter intake between treatments. Similar to the above study, Singh et al. (1999) found that inclusion of wheat bran at levels up to 77% of dietary concentrate in lamb diets did not affect dry matter intake.

The NDF content of diets has been shown to affect dry matter intake (Mertens, 1987; Schegettini et al. 1999; Tjardes et al. 2002; Voelker et al. 2007;). As the NDF content of the diet increases, it has both physical and mechanical effects on feed consumption (Voelker et al. 2007). Physically, NDF increases gut fill which limits the amount of feed animals can consume (Voelker et al. 2007). However, many factors influence the exact response that NDF will have on intake, including particle size and digestibility of the NDF (Poppi et al. 1980; Oba and Allen, 1999). Mertens (1987) stated that ruminants can consume up to 1.2% of body weight as NDF

before intake is negatively affected. Dietary NDF content is one reason that the results of the present study contrast with existing literature. The NDF content of the diets in the present trial is high at 42-43% in the control diet, 45-46% in the diets with 14% wheat bran and 47-49% in the diets with 28% wheat bran. As a percent of body weight, the animals were consuming 0.94, 1.07, and 1.15% of body weight as NDF in the 0, 14, and 28% wheat bran rations, respectively. Neutral detergent fibre consumption in this trial with the wheat bran diets was just under the levels (1.2% of body weight) at which NDF can limit dry matter intake (Mertens, 1987; Fox et al. 1990; Beauchemin, 1996). Forages with small particle size also pass through the rumen more quickly, which reduces gut fill and allows the animal to consume more feed (Poppi et al. 1980; Voelker et al. 2007). The average particle size of the wheat bran used in this trial was 0.52 ± 0.12 mm (Ro-Tap, Tyler Industrial Products, Mentor, OH.) which is significantly smaller than typical fibre sources such as silage or hay (Clark and Armentano, 2002).

Neutral detergent fibre digestibility is also a factor in regulation of dry matter intake. High quality forages are digested faster allowing the animal to consume more feed (Dado and Allen, 1996; Oba and Allen, 1999). Small ruminant trials (Singh et al. 1999; Dhakad et al. 2002) fed wheat bran at higher levels than the present trial, as well as a poorer quality roughage. The wheat straw fed by Dhakad et al. (2002) was analyzed at 77% NDF, which is 20% higher in NDF than both the grass hay and the barley silage fed in the present trial. Although NDF values were not reported by Singh et al. (1999), they also fed wheat bran at high levels with wheat straw as the roughage source. It is likely in both of these trials that at the highest level of wheat bran inclusion where performance started to decrease, NDF content and digestibility were limiting

Table 3.5 The effects of inclusion of wheat bran (WB) and/or condensed liquid whey (CLW) on performance and dietary net energy of gain of backgrounding calves^z

	Dietary Treatment								
	Wheat Bran			SEM	P-value	CLW		SEM	P-value
	Control	14%	28%			Control	4.6%		
		WB	WB				CLW		
Start of trial weight	294	294	294	0.24	0.22	294	294	0.2	0.60
End of trial weight	416	416	413	2.08	0.4	415	415	1.7	0.94
Average Daily Gain	1.37	1.35	1.32	0.020	0.35	1.34	1.35	0.021	0.91
Dry Matter Intake (kg/day)	8.77a	9.52b	9.76b	0.080	<0.0001	9.38	9.32	0.072	0.55
Dry Matter Intake (% BW)	2.20a	2.37b	2.43b	0.026	<0.0001	2.35	2.31	0.016	0.13
Feed: Gain	6.43a	7.04b	7.41c	0.103	<0.0001	7.00	6.93	0.080	0.60
NE _g of Diet (Mcal kg DM ⁻¹)	1.01a	0.93b	0.88b	0.02	<0.0001	0.93	0.95	0.010	0.32

^zmeans in the same row with different letters significantly differ (P<0.05)

intake. This was most likely not the case in the present trial as calves had dry matter intakes between 2.2 and 2.4% of body weight. When we look at dietary energy content, the 28% wheat bran rations had an average calculated NE_g of $0.88 \text{ Mcal kg}^{-1}$, while the NRC (2000) states NE_g requirements to be $0.92 \text{ Mcal kg}^{-1}$ to sustain a rate of gain of 1.1 kg d^{-1} . The NRC (2000) expects calves fed to the NRC (2000) requirements described in Table 3.1 to gain 1.14 kg d^{-1} and to consume 8.3 kg d^{-1} of DM. Calves in this trial gained 1.37, 1.35 and 1.32 kg d^{-1} in the control, 14 and 28% wheat bran diets, respectively, while they consumed 8.77, 9.52 and 9.76 kg d^{-1} of feed on a DM basis. The performance of the cattle illustrates that the diets in the current trial met the nutrient requirements of our animals as their performance exceeded predicted gains and intakes by the NRC (2000).

3.3.3 Live Animal Ultrasound Traits

The goal of the backgrounding period is to grow calves to maximum frame size and to put on protein without accumulating fat. Real-time ultrasound is a technique that can be used to monitor muscle and fat growth in live animals (Bergen et al. 1997). Ultrasound *l. dorsi* area is a measurement of muscle growth and thus protein deposition, while subcutaneous backfat measures fat deposition and can be used to determine when cattle are finished and ready for market. Table 3.6 shows *l. dorsi* area and subcutaneous backfat of cattle on the control and wheat bran diets. Treatment had no effect ($P > 0.05$) on the measured ultrasound carcass traits of *l. dorsi* area and subcutaneous backfat (Table 3.6). No significant ($P < 0.05$) main effects of either wheat bran or condensed liquid whey were seen and no wheat bran x condensed liquid whey interaction was found ($P > 0.05$). Cattle in the present trial gained only 1 to 2 mm of backfat, while they gained 9 to 10 cm^2 of *l. dorsi* area. This shows that the diets in this trial met the goals of the

Table 3.6 The effects of inclusion of wheat bran (WB) and/or condensed liquid whey (CLW) on ultrasound carcass traits of backgrounding calves

Dietary Treatment									
	WB			SEM	p-value	CLW		SEM	P-value
	Control	14% WB	28% WB			Control	4.6% CLW		
<i>US longissimus dorsi area (cm²)</i>									
Start of test	45.3	45.6	46.3	0.6	0.40	45.5	46.0	0.79	0.50
End of test	56.1	55.7	56.1	0.50	0.80	56.0	55.9	0.41	0.89
<i>US backfat thickness (mm)</i>									
Start of test	3.6	3.4	3.6	0.22	0.67	3.8	3.3	0.18	0.04
End of test	5.6	4.6	4.9	0.47	0.31	5.3	4.8	0.38	0.45
Backfat gain	2.0	1.6	1.1	0.38	0.28	1.6	1.6	0.31	1.00

backgrounding period which was to facilitate frame growth and protein accretion while minimizing fat deposition.

3.4 Conclusion

Replacing barley grain with wheat bran at levels up to 28% of diet dry matter resulted in increased feed intake, decreased feed efficiency and reduced dietary NE_g . However, average daily gain, ultrasound *l. dorsi* area and subcutaneous fat thickness were unaffected by the inclusion of wheat bran. These results indicate that wheat bran can replace barley grain at levels up to 28% of dietary dry matter in backgrounding diets without impacting average daily gain or carcass potential. However, calculated NE_g of diets containing wheat bran is lower than that of barley diets, so calves must consume more feed to sustain similar gains.

4.0 EFFECTS OF REPLACING BARLEY GRAIN WITH GRADED LEVELS OF WHEAT BRAN ON RUMEN FERMENTATION, VOLUNTARY INTAKE AND NUTRIENT DIGESTION

4.1 Introduction

As grain prices increase, the use of by-product feeds will become increasingly important for beef producers to remain profitable. By-products of the ethanol industry are becoming commonplace in animal feed, particularly in cattle rations. One relatively new by-product from wheat-based ethanol production is wheat bran, which is derived from abrasion milling of wheat prior to ethanol production. Wheat bran has been evaluated and available to the feed industry for many years (Hess et al. 1996; Singh et al. 1999; Dhakad et al. 2002). However, existing literature is based on wheat bran from flour milling as opposed to abrasion milling prior to ethanol production. Wheat bran is comprised mainly of fibrous material, mainly cellulose and hemicellulose. The NRC (2000) reports that wheat bran contains $42.8 \pm 8.7\%$ NDF and $14.0 \pm 1.5\%$ ADF compared to barley grain which is referenced as $18.1 \pm 4.8\%$ NDF and $5.8 \pm 2.2\%$ ADF.

Replacement of rapidly degradable carbohydrates such as the starch found in barley or corn grain, with structural carbohydrates, such as cellulose and hemicellulose, causes a shift in fermentation patterns within the rumen (Bauman et al. 1971; Bergman, 1990; Selmi et al. 2011). Fermentation of starch leads to increased ruminal propionate production while fermentation of fibrous material favours production of acetate (Bauman et al. 1971; Bergman, 1990; Selmi et al. 2011). Replacement of starch with more slowly digestible carbohydrate sources increases rumen pH and can be an important factor for mitigating rumen acidosis (Sung et al. 2007). The lack of

starch and the high structural carbohydrate content in wheat bran may cause higher rumen pH as well as an altered VFA profile in rumen fluid when compared to barley grain. Hess et al. (1996) found no change in rumen pH, acetate, propionate or total VFA levels between grazing calves supplemented with wheat bran or corn grain, but did find that butyrate and isobutyrate were increased in corn diets when compared to wheat bran diets.

There is very little data on the digestibility of wheat bran. Singh et al. (1999) found that digestibility of DM, OM, nitrogen free extract and total carbohydrates were unaffected when 50% of grain in lamb diets was replaced with wheat bran. However, when 100% of the grain was replaced, digestibility of these nutrients was negatively affected.

No research has been conducted to evaluate the effects of wheat bran from abrasion milling prior to ethanol production on feed intake and subsequent nutrient digestion by cattle. The objectives of this trial were to compare cattle fed barley grain to those fed graded levels of wheat bran in terms of rumen fermentation parameters, voluntary DM intake and total tract nutrient digestibility.

4.2 Materials and Methods

4.2.1 Experimental Design, Animals and Housing

Five rumen cannulated and spayed purebred Angus heifers (584±40 kg) were housed in the metabolism barn at the University of Saskatchewan. The individual floor pens were 9 m² and were fitted with individual feed bunks, water bowls and rubber floor mats. The heifers were processed with the same receiving protocol as the steers in Trial 1. Each heifer was randomly assigned to one of five treatments in a 5x5 Latin square design. The trial duration was 145 days

and consisted of five periods, each of which was 29 days in length. The first 7 days of each period were used for diet adaptation. Voluntary intake was measured on d 8 to 14. For the remainder of each period cattle were fed 95% of voluntary intake to assure consumption of all feed. On d 15, 24 h rumen fluid collections took place. Days 17 to 21 were used for passage rate sampling, while d 21 to 24 were for measurement of rumen fluid pH using in-dwelling pH probes and d 25 to 29 for total collection of feces and urine.

4.2.2 Treatments, Feeding and Diet Composition

The control ration consisted of 35.9% barley silage, 24.4% grass hay, 31.4% barley grain and 8.3% mineral and vitamin supplement, and was formulated for a NE_m of 1.50 and NE_g of 0.91 Mcal kg^{-1} (DM basis). The remaining four dietary treatments replaced barley with wheat bran at 8, 16, 24 and 32% of diet DM (Table 4.1). Wheat bran used in this trial was the same as that used in the growth trial and was obtained from Pound-Maker Agventures Ltd. in Lanigan, SK. Wheat bran was stored outdoors under a covered roof. The barley grain was purchased from commercial sources (60.5 kg hL^{-1}) and was dry rolled to a processing index of 77.1% (RossKamp Champion, Waterloo, IA). Barley silage (AC Rosser) was grown at the University of Saskatchewan and stored in a bunker silo. The brome/alfalfa hay was grown at the University of Saskatchewan and ground in a tub grinder (Haybuster H-1000, DuraTech Industries International, Jamestown, ND.) through a 9.5 cm screen. Individual feed ingredients were sampled each period and composited for analysis.

Table 4.1 Composition and Analysis of Metabolic Trial Rations

	Treatment				
	Control	8% Wheat Bran	16% Wheat Bran	24% Wheat Bran	32% Wheat Bran
<i>Diet Composition (%DM Basis)</i>					
Barley Silage	35.9	35.8	35.7	35.6	35.5
Grass Hay	24.4	24.3	24.3	24.2	24.1
Barley Grain	31.4	23.3	15.8	8.0	-
Wheat Bran	-	8.3	16.0	24.0	32.2
Supplement	8.3	8.3	8.2	8.2	8.2
<i>Supplement Composition (%DM Basis)</i>					
Barley	74.2	74.2	74.2	74.2	74.2
Canola Oil	3.3	3.3	3.3	3.3	3.3
Limestone	5.6	5.6	5.6	5.6	5.6
Vitamin Premix ^x	5.9	5.9	5.9	5.9	5.9
Ionophore premix ^y	5.9	5.9	5.9	5.9	5.9
Trace mineral salt ^z	5.1	5.1	5.1	5.1	5.1
<i>Ration Analysis (DM Basis \pm SD)</i>					
Organic matter	93.5 \pm 0.02	93.3 \pm 0.02	93.2 \pm 0.03	93.1 \pm 0.09	92.8 \pm 0.09
Crude Protein	11.8 \pm 0.001	12.0 \pm 0.06	12.0 \pm 0.02	12.2 \pm 0.002	12.2 \pm 0.06
Acid detergent fibre	23.3 \pm 0.004	23.9 \pm 0.006	24.3 \pm 0.12	25.0 \pm 0.009	25.6 \pm 0.004
Neutral detergent fibre	38.3 \pm 0.004	39.8 \pm 0.006	40.7 \pm 0.32	42.6 \pm 0.01	44.0 \pm 0.006
Gross Energy (cal g ⁻¹)	4035.9 \pm 0.05	4070.9 \pm 0.06	4101.9 \pm 0.95	4137.2 \pm 0.08	4171.1 \pm 0.09

^xUniversity of Saskatchewan vitamin A & D supplement = 440,500 IU vitamin A, and 88,000 IU vitamin D3 kg⁻¹

^yUniversity of Saskatchewan Feed Unit Ionophore Premix: contains 96.77 % barley and 3.23 % Rumensin® Premix containing monensin (as monensin sodium) at 200 g kg⁻¹ (Elanco, Guelph, ON) (DM basis)

^zTrace mineral salt: 95 % NaCl, 12, 000 ppm Zn, 10, 000 ppm Mn, 4,000 ppm Cu, 400 ppm I, 60 ppm Co, 30 ppm Se

Rations were formulated to meet or exceed NRC (2000) requirements for medium frame backgrounding cattle as described in Trial 1(NRC, 2000) for vitamins, minerals, energy and CP. Animals were fed twice daily at 0800 and 1600 h. Prior to morning feeding, bunks were swept out and orts recorded. To determine voluntary feed intake, heifers were fed to have 5 to 10% orts remaining in their bunk. Heifers were weighed every period prior to and at the end of the voluntary intake phase. Water was available *ad libitum*.

4.2.3 Rumen Metabolism

4.2.3.1 In-Dwelling Rumen pH Measurement

On d 21 in-dwelling pH probes with data loggers (Dascor, Escondido, CA) were inserted into the ventral sac of the rumen of each heifer as outlined by Penner et al. (2006). These probes allow rumen pH to be measured every 30 seconds for the time they are in the rumen. Probes were inserted prior to 0800 on d 21 and removed 72 hours later on d 24. After removal, the data was downloaded and the probes were recalibrated and cleaned (Penner et al. 2006).

The pH data was summarized by minute and adjusted with Microsoft Excel (2007) according to calculated slope and y-intercept values determined during calibration to summarize mean, maximum and minimum pH. The duration (min d^{-1}) and area ($\text{min d}^{-1} \times \text{pH}$) under the pH threshold of 5.8 were determined. The pH of 5.8 was used as a threshold below which animals are considered to be experiencing mild acidosis as defined by Penner et al. (2006).

4.2.3.2 Solid Phase Passage Rate Marker Preparation

Wheat straw mordanted with chromium (Cr) was used as a solid phase rumen passage rate marker. The straw was prepared as outlined by Uden et al. (1980) and Zhang (2008) by first grinding wheat straw through a 2 mm screen with a lab scale hammer mill (Christie Norris Laboratory Mill Size 8", Christie-Norris Ltd. Chelmsford, United Kingdom) and then boiled for 1.5 h in water containing powdered laundry detergent. After the straw was rinsed clean of laundry detergent, it was then boiled for 1.5 h in neutral detergent solution to remove all soluble materials. The straw was then rinsed until completely free of bubbles and dried at 60 °C for 48 h. Sodium dichromate dihydrate ($\text{Na}_2\text{Cr}_2\text{O}_7 \cdot 2\text{H}_2\text{O}$) solution was then added to the remaining dry straw at a concentration of 40.11 g $\text{Na}_2\text{Cr}_2\text{O}_7 \cdot 2\text{H}_2\text{O}$ and 600 mL of distilled deionized water (ddH₂O) for every 100 g of straw being mordanted. The Cr-mordanted straw was then covered with aluminum foil and baked in an oven at 100 °C for 24 h. The straw was then vacuum filtered and rinsed with ddH₂O until free of colour and bubbles. Ascorbic acid was then added to the straw at a concentration of 50 g of ascorbic acid and 2500 mL of ddH₂O per 100 g of fibre. This was then allowed to sit overnight and the Cr-mordanted straw was then rinsed again until the rinse water was clear and no longer green. The Cr-mordanted straw was then dried at 60°C for 48 h and was ready for insertion into the rumen.

4.2.3.3 Liquid Phase Passage Rate Marker Preparation

Rumen fluid passage was measured using cobalt ethylenediaminetetraacetic acid (Co-EDTA) as a liquid phase passage rate marker. Co-EDTA crystals were prepared using the method outlined by Uden et al. (1980) and Penner et al. (2009). To prepare the crystals, 300 g of cobaltous acetate, 350 g of EDTA, 48 g of sodium hydroxide and 2 L of ddH₂O were added to a

4 L beaker and stirred over medium heat on a stirring hot plate for 4 to 5 h. The solution was then brought back up to volume and allowed to continue stirring on low heat overnight. The beaker was then placed on ice and 240 mL of hydrogen peroxide was added and the mixture was stirred for 5 to 6 h. Ethanol was then added to the solution and the solution refrigerated overnight to facilitate crystallization. The solution was then filtered to remove crystals. The crystals were rinsed with ethanol to remove impurities. Crystals were then dried in an oven at 60°C. To prepare for insertion into the rumen, 125 g of Co-EDTA was dissolved in 450 mL of ddH₂O to make one dose of cobalt EDTA solution.

4.2.3.4 Insertion of Solid and Liquid Phase Passage Rate

Markers

On d 17, a background sample was taken approximately 1 h prior to insertion of passage rate markers. Approximately 6 to 7 kg of rumen contents were removed from the rumen of each heifer and placed in a Rubbermaid tub. After evacuation of rumen contents, one dose of Co-EDTA was inserted into the rumen via a piece of Nalgene tubing. The Co-EDTA solution was inserted using a funnel and rumen contents were mixed thoroughly by hand. Following this, 100 g of Cr-mordanted fibre was added to the evacuated rumen contents and mixed thoroughly. Rumen contents were then placed back into the rumen making sure none was left in the tub or spilled onto the ground. Samples of rumen digesta were then taken at 0.5, 1, 2, 3, 6, 9, 12, 18, 24, 36, 48, 72 and 96 hours after insertion. Samples were squeezed through four layers of cheesecloth. Rumen fluid was retained for analysis of cobalt and solid digesta for analysis of chromium.

4.2.3.5 Rumen Fluid Collections

On d 15 of each period rumen fluid was sampled every two hours for a 24 h period. Sampling began at 0800 on d 15 and ended at 0600 on d 16. Approximately 250 mL of rumen fluid was taken from four different regions of the rumen (rumen mat, ventral sac, caudal sac and reticulum). The digesta was then strained through four layers of cheese cloth. The pH of the rumen fluid was taken in duplicate immediately after straining with a model 265A portable pH meter (Orion Research Inc., Beverly, MA). Rumen fluid was kept frozen at -20°C for analysis of volatile fatty acids (10ml of rumen fluid combined with 2 mL of 25% metaphosphoric acid solution) as well as for rumen ammonia-N (10 mL of rumen fluid combined with 2 mL of 1% sulphuric acid solution).

4.2.3.5.1 Volatile Fatty Acid Analysis

Analysis of VFAs was carried out at the Agriculture and Agri-Food Canada Research Centre in Lethbridge AB. Rumen fluid samples used for VFA analysis were thawed overnight at 4 °C prior to analysis. Samples were centrifuged for 2 min at 5,000 x g. After this, 1.2 mL of the supernatant was transferred into a new micro-centrifuge tube and 0.2 mL of crotonic acid solution added as an internal standard. Samples were then allowed to stand at room temperature for 30 min and then centrifuged for 10 min at 14,000 x g. The supernatant was then transferred into an autosampler vial. A Hewlett Packard 5890 gas chromatography system with splitless injection capability and fitted with a Supelco Nukol polar capillary GC column was used to identify and quantify VFAs (acetate, propionate, butyrate, isobutyrate, valerate and isovalerate) in each sample. A standard curve was prepared using purchased standards (Sigma Aldrich) in order to quantify (mM) individual VFAs.

4.2.3.5.2 Rumen Ammonia-N Analysis

Samples were thawed overnight at 4°C and then centrifuged at 14,000 x g for 10 minutes at 4°C. The phenol hypochlororite procedure described by Broderick and Kang (1980) was used to quantify ammonia in rumen fluid samples.

4.2.4 Voluntary Intake

Voluntary intake was measured from d 8 to 14 of each period. Heifers were fed to have 5 to 10%orts remaining in the bunk to ensure *ad libitum* intake. Orts were removed and weighed each morning and voluntary intake was calculated as the feed provided minus the feed remaining in the bunk.

4.2.5 Total Tract Collections

Total fecal and urine collections were performed for the last five days of each period to determine nutrient digestibility. Heifers were haltered in their pens with enough room for standing, lying, eating and drinking. Bladder catheters (Bardex Foley Catheter, 75 mL capacity balloon; C. R. Bard Inc., Covington, GA.) were inserted by a veterinarian 24 h prior to the beginning of collection. Urine was collected via sterile Nalgene tubing connected to the bladder catheter and to Nalgene jugs containing 125-150 mL of hydrochloric acid. HCl was used to reduce the pH of the urine to 2.0 so that volatilization of ammonia would be minimized (Stockdale and Rathbone, 1992). Daily urine output was recorded. The urine was then thoroughly mixed, the pH checked with a portable pH meter to ensure acidification (Model 265A portable pH meter, Orion Research Inc., Beverly, MA) and 20% of daily output was saved and

frozen. At the end of each total collection period all urine for that period was thawed, combined and a 1 litre composite sample was taken and frozen for later analysis of total nitrogen.

Total fecal output was measured by scraping feces off of the floor every two hours throughout the day. Feces were placed in a sealed container after collection. Wet fecal output was recorded daily. Feces were mixed thoroughly and each day two 500 g samples were taken. One sample was placed in the oven and dried at 55 °C for 96 h while the other was frozen at -20 °C for N analysis.

4.2.6 Chemical Analysis

Dried samples of feed ingredients and feces were ground through a 1 mm screen with a lab scale hammer mill (Christie Norris Laboratory Mill Size 8", Christie-Norris Ltd. Chelmsford, United Kingdom). All feed and fecal samples were analyzed in duplicate for dry matter (AOAC method 930.15), crude protein using a nitrogen conversion factor of 6.25 (AOAC method 984.13), neutral detergent fibre (AOAC method 2002.04), and acid detergent fibre (AOAC method 973.18). Gross energy was also determined by bomb calorimetry. Urinary nitrogen was analyzed using a Kjeldahl to analyze liquid samples.

Solid rumen contents for passage rate determination were dried at 55 °C for 72 h and ground through a 1 mm screen (Christie Norris Laboratory Mill Size 8", Christie-Norris Ltd. Chelmsford, United Kingdom). The solid samples were then digested following the procedure of Williams et al. (1962) and analyzed for chromium and read on a Varian SpectrAA 220 atomic absorption spectrometer (Varian Analytical Instruments, Australia). Rumen fluid was dried, ashed, digested with 12 N sulphuric acid solution (Penner et al. 2009) and cobalt concentration

was read on a Varian SpectrAA 220 atomic absorption spectrometer for cobalt concentration (Varian Analytical Instruments, Australia).

4.2.7 Statistical Analysis

Voluntary intake and nutrient digestibility were analyzed as a Latin square design using the mixed model procedure of SAS (Version 9.2; SAS Institute, Inc. Cary, N.C., USA) with the random effect of heifer and the fixed effects of treatment and period. Rumen pH, VFA and ammonia data were analyzed as a Latin square design with repeated measures. Significance was discussed at $P < 0.05$ and trends at $P < 0.10$. Polynomial contrasts were used to determine linear, quadratic, cubic and quartic effects of wheat bran inclusion rate.

4.3 Results and Discussion

4.3.1 Diet Composition and Analysis

The composition of diets fed in this trial is given in Table 4.1. The wheat bran and barley grain samples were a composite collected throughout the trial. The chemical composition of the wheat bran fed in this trial was 12.8% CP, 36.6% NDF, 13.4% ADF and 4.4% ash (DM basis). The chemical composition of the rolled barley fed in this trial was 11.4% CP, 18.2% NDF, 5.7% ADF and 2.4% ash (DM basis). Similar to Trial 1, the NDF and ADF content of the experimental diets increased as the wheat bran inclusion rate increased. Neutral detergent fibre content of the control diet was 38.3% (DM basis) and in the 8, 16, 24, and 32% wheat bran diets, NDF content was 39.8, 40.7, 42.6 and 44.0% (DM basis) respectively. Acid detergent fibre content of the control diet was 23.3% (DM basis) and increased to 23.9, 24.3, 25.0 and 25.6% in the 8, 16, 24 and 32% wheat bran diets respectively. The gross energy content of the diets was also increased

as wheat bran inclusion level increased and went from 4035.9 cal g⁻¹ in the control diet to 4079.9, 4101.9, 4137.2 and 4171.1 cal g⁻¹ in the 8, 16, 24 and 32% wheat bran diets, respectively. Crude protein content was similar across diets, averaging 12.0%

4.3.2 Voluntary Intake

No effect ($P>0.05$) of treatment was observed on voluntary DM or OM intake measured as kg d⁻¹ or as a percent of body weight (Table 4.2). In agreement with our results, Dhakad et al. (2002) found no effect on intake when measured as g d⁻¹ when corn grain was replaced at 50 or 100% with wheat bran in concentrate mixtures for growing lambs fed wheat straw. Singh et al. (1999) also found no effect on intake when 50 or 100% of barley grain was replaced with wheat bran in concentrate mixtures for adult sheep fed wheat straw *ad libitum*. In addition, both Hess et al. (1996) and Dhakad et al. (2002) found no effect on intake as a percent of body weight when corn grain was replaced with wheat bran in diets for calves and lambs, respectively.

These results differ somewhat with the backgrounding trial conducted as part of this study, where it was found that DMI increased ($P<0.05$) as the level of wheat bran increased. In the current metabolic trial, animals were housed in individual pens, while in the other referenced studies (Hess et al. 1996; Singh et al. 1999; Dhakad et al. 2002) as well as the backgrounding trial done as part of this research, group housing was used. Past studies have shown that cattle eat more when group fed, as opposed to individual feeding, due to within pen competition for feed (Coppock et al. 1972; Warnick et al. 1977). These differences in housing and competition for feed help explain why intake was not affected by treatment in Trial 2, yet increased in Trial 1. As will be discussed, decreased nutrient utilization of wheat bran diets also played a role.

4.3.3 Rumen pH (In-Dwelling and Spot Samples)

The mean rumen pH for both spot sample and in-dwelling pH measurements was not different ($P>0.05$) between treatments (Table 4.2). There was a significant effect of time

Table 4.2 Effect of replacement of barley grain with wheat bran (WB) at 8, 16, 24 and 32% of dietary dry matter intake, organic matter intake and rumen pH measurements

	Dietary Treatment					SEM ^Z	P-value Contrasts ^X	
	Control	8% WB	16% WB	24% WB	32% WB		Linear	Quadratic
<i>Dry Matter Intake</i>								
% body weight	1.88	1.84	1.84	1.83	1.81	0.046	0.30	0.90
kg d ⁻¹	11.79	11.59	11.79	11.77	11.24	0.320	0.19	0.32
<i>Organic Matter Intake</i>								
% body weight	1.74	1.71	1.71	1.71	1.68	0.041	0.36	0.98
kg d ⁻¹	11.01	10.81	10.96	10.94	10.44	0.305	0.13	0.32
<i>Mean Daily Rumen pH</i>								
Spot Sample	6.27	6.24	6.21	6.34	6.31	0.129	0.66	0.75
In Dwelling	6.31	6.34	6.57	6.38	6.36	0.109	0.68	0.22
Maximum Daily pH	6.99	7.01	7.14	6.92	6.89	0.113	0.44	0.29
Minimum Daily pH	5.66	5.69	5.64	5.66	5.67	0.113	1.00	0.93
<i>Rumen pH Parameter 5.8 or lower</i>								
Mean pH	5.67	5.67	5.65	5.67	5.70	0.029	0.52	0.41
Total Duration (min d ⁻¹)	179	196	233	162	149	71.1	0.68	0.53
pH area (pH * min)	32.06	54.66	26.38	24.17	15.91	18.482	0.27	0.60

^Z pooled standard error of the mean

^X cubic and quartic contrasts of wheat bran inclusion rate were not significant ($P>0.05$)

($P<0.05$) (Figure A.3). This was expected as rumen fermentation parameters exhibit a diurnal pattern when cattle are fed twice daily (France and Dijkstra, 2005; Nagaraja and Titgemeyer, 2007). There was no ($P>0.05$) treatment x time interaction. There was no difference ($P>0.05$) between treatments in rumen pH parameters under pH 5.8, including min d⁻¹ and area under pH

5.8 (pH x min). Maximum and minimum pH values did not vary ($P>0.05$) between treatments. Although measured pH parameters were not affected by treatment, they do illustrate that rumen fermentation conditions were resulting in minimal acidosis. Mild acidosis is defined as time or area under a rumen pH cut off value of 5.8, while moderate and severe acidosis are measured by area under pH 5.5 and 5.2, respectively (Nocek, 1997; Beauchemin and Yang, 2005; Penner et al. 2007). As seen in Table 4.2, all diets had mean pH of at least 6.3 and spent less than 4 hours per day under pH 5.8.

Wheat bran is lower in starch and higher in both NDF and ADF than barley grain. These fibrous compounds are more slowly degraded by rumen microbes and, therefore VFAs are produced by microbes at a slower rate than with starch digestion (Nagaraja et al. 2007). Dado and Allen (1995) found that dairy cows consuming diets lower in NDF had a lower mean rumen pH and spent more time under pH 5.5. Coe et al. (1999) found that cattle consuming alfalfa hay had markedly lower levels of VFAs in the rumen and a higher mean rumen pH than the same cattle after switching to diets containing 70, 85 or 100% concentrate. Similarly, Leedle et al. (1995) found that the rumen VFA concentration increased and the rumen pH decreased as cattle were given weekly increases in concentrate (25, 50, 75 and 90% concentrate). Not only does the amount of NDF in the diet affect rumen pH, but the physical characteristics of the NDF source are also important (Yang and Beauchemin, 2006). Although wheat bran is high in NDF, the particle size of wheat bran used in this trial averaged 0.52 ± 0.12 mm. Yang and Beauchemin (2006) stated that fibre sources with a particle size greater than 5 mm stimulate chewing, which helps to mitigate acidosis through bicarbonate from increased saliva production.

The increase in NDF and ADF in diets containing wheat bran is counteracted by the fact that the fibre is not of a large enough particle size to stimulate chewing. Therefore, no extra

bicarbonate reaches the rumen and as a result rumen pH between the control and the wheat bran diets does not vary. Also contributing to the lack of change in rumen pH levels, is the fact that grain was fed at low levels (32% dietary DM), even in the control diet. Fermentation of forages is slower than that of grain and therefore acid is not produced as quickly in the rumen and does not accumulate to the same degree as in diets with high concentrate levels (Nagaraja and Titgemeyer, 2007).

4.3.4 Rumen Fermentation Parameters

There was a significant ($P < 0.01$) effect of time for all VFA measurements as well as rumen $\text{NH}_3\text{-N}$ (Figure A.2). This is to be expected as rumen fermentation shows a diurnal pattern after feeding with a spike in both VFAs and rumen $\text{NH}_3\text{-N}$ occurring after both morning and afternoon feedings (France and Dijkstra, 2005; Nagaraja and Titgemeyer, 2007). There was no significant ($P > 0.05$) treatment x time interaction (Table 4.3). Acetate was increased ($P < 0.05$) in a linear fashion as wheat bran was added to diets. There was no effect ($P > 0.13$) of treatment on propionate level or any other ($P > 0.12$) measured VFA. Total volatile fatty acid concentration was not affected by treatment ($P = 0.67$) and values were typical of those seen on high fibre, backgrounding diets (Bergman, 1990; Selmi et al. 2011). The acetate to propionate ratio (A:P) ranged from 3.13 to 3.60, which is again typical for rumen fermentation of forage-based diets which favours the production of acetate (Bergman, 1990; Dijkstra, 1994; Sutton et al. 2003; Selmi et al. 2011). Hess et al. (1996) found that there was no difference in total VFAs or A:P between calves on pasture supplemented with corn or wheat bran. Although Hess et al. (1996) found no increase in acetate, as in the current trial, they reported a similar A:P (3.5 to 3.8).

The increase in acetate and high A:P ratio observed as a result of wheat bran inclusion was expected as wheat bran is higher in NDF and ADF than barley grain. The nature of the diets may help to explain why there were minimal effects of wheat bran inclusion on rumen fermentation. All diets were high in roughage (>60% DM basis) and low in concentrate. As a result, observed rumen fermentation parameters, including pH, VFA levels and A:P, even for the barley-based control diet already reflected a pattern consistent with high fibre diets (Sutton et al. 2003; Christopherson et al. 2008;). As a result, replacing barley grain with wheat bran did not change these parameters to any great extent.

Treatment had no affect ($P>0.05$) on rumen $\text{NH}_3\text{-N}$ levels. These results disagree with those of Hess et al. (1996) who found that rumen $\text{NH}_3\text{-N}$ levels were increased ($P<0.05$) when calves on pasture were fed wheat bran as a supplement instead of corn. However, it should be noted that the diets in the current trial were essentially isonitrogenous (ranging from 11.8 to 12.2% CP). Therefore, one would not expect any differences in rumen $\text{NH}_3\text{-N}$ unless there are major differences in the soluble protein content of wheat bran and barley grain. No research exists on the rumen undegradable protein (RUP) content of wheat bran from abrasion milling prior to ethanol production, but the NRC (2000) indicates that wheat bran protein has $20 \pm 10\%$ RUP, while the RUP content of barley grain is listed at $26 \pm 10\%$. These numbers are similar and both have high SD and thus one would not expect major differences in rumen ammonia-N levels when one is substituted for the other. In contrast, diets fed by Hess et al. (1996) were not isonitrogenous with both the unsupplemented control and the corn treatment being lower in CP than the wheat bran treatment.

Table 4.3 Effects of replacing barley grain with wheat bran (WB) at 8, 16, 24 and 32% of dietary DM on rumen volatile fatty acids (VFAs) and rumen ammonia nitrogen (NH₃-N)

	Dietary Treatment					SEM ^Z	P-value Contrasts ^X	
	Control	8%	16%	24%	32%		Linear	Quadratic
		WB	WB	WB	WB			
<i>VFA (mmol 100 mol⁻¹)</i>								
Acetate	63.40	64.11	64.86	65.96	66.12	1.002	0.03	0.85
Propionate	21.20	20.38	19.15	19.33	18.66	1.217	0.13	0.71
Butyrate	10.90	11.07	11.59	10.39	11.17	0.593	0.94	0.83
Isobutyrate	0.92	0.90	0.91	0.92	0.88	0.098	0.83	0.89
Valerate	1.46	1.47	1.44	1.43	1.38	0.037	0.13	0.48
Isovalerate	1.58	1.47	1.49	1.41	1.31	0.094	0.12	0.86
Total VFA (mmol L ⁻¹)	103.77	102.77	102.55	100.41	99.55	7.917	0.67	0.96
A:P Ratio	3.14	3.30	3.43	3.46	3.60	0.280	0.23	0.90
Rumen NH ₃ -N (mg dL ⁻¹)	5.21	5.58	5.69	5.41	7.25	0.877	0.17	0.45
<i>Passage Rate (% h⁻¹)</i>								
Particulate	6.4	5.9	4.4	4.0	3.8	1.59	0.29	0.51
Fluid	18.5	18.3	16.0	17.1	17.9	3.01	0.59	0.26

^Z Pooled standard error of the mean

^X Cubic and quartic effects of wheat bran inclusion level were not significant (P>0.05)

Ammonia-N is a crucial source of N for rumen bacteria (Boucher et al. 2007; Cole and Todd, 2008). Boucher et al. (2007) states that for optimum rumen fermentation and microbial protein synthesis, rumen $\text{NH}_3\text{-N}$ values should be in the range of 2 to 13 mg dL^{-1} . The values from the current trial range from 5.2 to 7.2 mg dL^{-1} which is well within this range. Cellulolytic bacteria prefer to use N that is in the form of NH_3 . It stands to reason that cellulolytic bacteria in the rumen of cattle fed the barley and wheat bran diets were not limited in growth due to shortage of $\text{NH}_3\text{-N}$ (Cole and Todd, 2008; Moya et al. 2009).

4.3.5 Digestibility

Increasing the inclusion of wheat bran linearly reduced ($P<0.01$) DM and OM ($P<0.01$) digestibility (Table 4.4). The magnitude of this decrease was 7.0 and 6.9% for DM and OM, respectively, when the control diet was compared to the 32% wheat bran diet. Dhakad et al. (2002) found no difference in DM or OM digestibility when corn grain was replaced with wheat bran at 25, 50 and 75% of dietary concentrate. In agreement with the current trial, Singh et al. (1999) also noted a reduction in digestibility of DM and OM; however, only when levels of wheat bran reached 77% of dietary concentrate. The reduction in DM and OM digestibility in this trial could be due to the higher NDF and ADF intake in diets containing wheat bran. For example, the 32% wheat bran diet contained 44.0% NDF and 25.6% ADF compared to the control diet which contained 38.3 and 23.3% NDF and ADF, respectively.

Neutral ($P<0.05$) and acid detergent fibre ($P<0.05$) digestibility decreased in a quadratic fashion as wheat bran inclusion rate increased (Table 4.4). The largest drop in both NDF and ADF digestibility was seen at the 8% inclusion rate with minimum digestibility values seen at the 16% inclusion level. Dhakad et al. (2002) found that digestion of both NDF and ADF of diets

consisting of wheat straw supplemented with a concentrate mixture in which corn grain was replaced with wheat bran were unaffected by inclusion of wheat bran. Contrary to this, Singh et al. (1999) found that digestibility of crude fibre was improved as wheat bran was added to diets consisting of wheat straw along with a concentrate mixture in which 50 or 100% of barley grain was substituted for wheat bran. Singh et al. (1999) attributed this increase in digestibility to increased retention time in the rumen, although in the current trial no significant difference was seen in rumen passage rate. Inclusion of wheat bran had no effect on CP digestibility. This is in agreement with other studies as both Dhakad et al. (2002) and Singh et al. (1999) reported that the digestibility of CP was unaffected by replacement of barley or corn grain by wheat bran in concentrate mixtures for sheep. Gross energy digestibility decreased ($P=0.05$) in a linear fashion as wheat bran inclusion rate increased while digestible energy content (Mcal kg^{-1}) tended to decrease ($P=0.06$) in a quadratic fashion as wheat bran inclusion rate increased. The largest drop in DE was seen at the 8% wheat bran inclusion level and thereafter leveled at about 2.8 Mcal kg^{-1} (DM basis) as wheat bran inclusion level increased (Table 4.4).

Table 4.4 Apparent nutrient digestibility coefficients, dietary digestible energy (DE) content and nitrogen balance of heifers fed backgrounding diets containing 0, 8, 16, 24 and 32% wheat bran (WB)

		Dietary Treatment					P-value Contrasts ^x	
		Control	8% WB	16% WB	24% WB	32% WB	SEM ^z	Linear Quadratic
<i>Apparent Nutrient Digestibility Coefficient (%)</i>								
	Dry matter	72.52	69.04	67.94	68.45	67.40	1.058	<0.01 0.09
	Organic Matter	74.24	71.09	69.77	70.23	69.14	1.014	<0.01 0.11
	Crude Protein	70.39	67.59	66.82	68.77	70.01	1.736	0.94 0.11
	Neutral Detergent Fibre	56.65	51.35	49.67	51.48	49.93	1.435	<0.01 0.03
	Acid Detergent Fibre	54.19	48.67	47.91	48.76	48.87	1.457	0.01 0.01
	Gross Energy	71.72	68.18	67.26	67.94	67.32	1.133	0.02 0.08
Σ	Digestible Energy (Mcal kg ⁻¹)	2.90	2.77	2.75	2.81	2.81	0.047	0.30 0.06
	Fecal Output (kg d ⁻¹)	3.13	3.59	3.65	3.68	3.57	0.137	0.05 0.04
	Urine Output (L d ⁻¹)	9.92	9.67	10.37	8.42	9.53	0.776	0.38 0.98
<i>Nitrogen (g d⁻¹)</i>								
	Total N intake	195.2	206.4	208.6	205.1	199.1	6.06	0.57 0.01
	Total N excreted	166.7	187.5	190.5	176.4	182.8	10.12	0.75 0.83
	Feces	54.0	64.0	65.4	66.0	64.6	2.64	0.02 0.03
	Urine	112.2	124.2	125.6	110.0	118.1	8.86	0.94 0.49
	Apparent Nitrogen Retention	27.6	19.8	15.6	29.5	18.1	9.75	0.77 0.77

^z Pooled standard error of the mean

^x Cubic and quadratic effects of WB inclusion rate were not significant (P>0.05)

4.3.6 Passage Rate

No treatment differences ($P>0.05$) were noted in either rumen particulate or fluid passage rate (Table 4.3). Particulate or solid passage ranged from 6.4% h^{-1} in the control diet to 3.8% h^{-1} in the 32% wheat bran diet. Passage of the fluid phase was highest in the control diet at 18.5% h^{-1} and lowest in the 16% wheat bran diet at 16.0% h^{-1} . These values for particulate passage rate are fairly typical of what is seen in the literature. Oshita et al. (2008) found that dairy cows grazing pasture had rumen particulate passage rates of 8.5% h^{-1} , while Berzaghi et al. (1996) found that particulate passage rate in grazing dairy cows ranged from 6.7 to 7.5% h^{-1} . Lower values have been reported as well. Meta analysis by Krizsan et al. (2011) looking at 29 studies found an average particulate passage rate of 2.45% $\text{h}^{-1} \pm 0.6\%$ with a maximum particulate passage rate of 4.25% h^{-1} . The average forage content of the treatments evaluated in the meta analysis was 40 to 50% (DM basis) which was lower than that fed in the current trial (60% forage; DM basis).

The rumen fluid passage rate of dairy cows grazing pasture has been reported to be from 15.5 to 18.5% h^{-1} (Berzaghi et al. 1996; Oshita et al. 2008). However, values for cattle consuming diets based on hay or silage as in the current trial vary from 10 to 20% per hour (Hartnell and Satter, 1979; Berzaghi et al. 1996; Oshita et al. 2008). The fluid passage rates in this trial were very similar to those reported in grazing dairy cows consuming a 100% forage diet (Berzaghi et al. 1996; Oshita et al. 2008).

Data on the effects of wheat bran on rumen passage rate are limited. Hess et al. (1996) also found no effect of treatment on rumen particulate and fluid passage rates of calves grazing pasture supplemented with corn grain or wheat bran. These workers reported values for passage

rate that were from 3.3 to 3.7% h⁻¹ for particulate matter and 12.9 to 13.9% h⁻¹ for fluid phase passage. These values, particularly those for fluid passage rate are lower than those in the present study and those in the studies by Oshita et al. (2008) and Berzaghi et al. (1996), who also measured the passage rate of cattle grazing pasture. Rumen passage rate is partially controlled by physical factors of feed including particle size and specific gravity as well as the level of feed intake and the rate of feed digestion (Church, 1969; Allen, 2000). Wheat bran used in this study had an average particle size of 0.52 ± 0.12 mm, which may have contributed to the relatively high rate of passage observed in the current trial. Fibrous material with a small particle size will pass through the rumen more quickly than the same type of fibre with a longer particle size (Beauchemin and Yang, 2005; Van Soest, 1994). Uden et al. (1988) and Robinson et al. (1987) both state that feed with lower digestible fibre content will cause a decrease in particulate passage rate. Digestibility results (Table 4.4) of this trial show that fibre (NDF and ADF) digestibility is decreased as wheat bran is added to diets. Although the results of this trial do not show a significant decrease in passage rate, passage rate becomes numerically less with increasing wheat bran inclusion rate. This helps to explain the decrease in digestibility of both NDF and ADF observed in Table 4.4.

4.3.7 Nitrogen Excretion

Nitrogen intake increased ($P < 0.05$) in a quadratic fashion as wheat bran inclusion increased. The largest increase was seen at the 8% wheat bran inclusion level with maximum intake seen at 16% wheat bran. The magnitude of this increase was not great however (Table 4.4), and likely reflects slightly higher dietary CP levels of the wheat bran diets (Table 4.1). There was no effect of treatment ($P = 0.75$) on total N excretion. However, fecal N excretion increased ($P < 0.05$) in a quadratic fashion as wheat bran inclusion level increased (Table 4.4),

with the largest increase in fecal N seen at 8% wheat bran inclusion and subsequently plateauing at 65 g d⁻¹ at higher inclusion levels. There was no effect (P=0.49) of treatment on urinary N excretion.

The increase in fecal N with increasing inclusion level of wheat bran suggests that wheat bran protein is less digestible than barley protein. Fecal N output was increased by 16, 18, 19 and 17% for the 8, 16, 24 and 32% wheat bran diets, respectively, when compared to the control diet. It is also possible that hind gut fermentation increased as wheat bran inclusion level increased due to increased carbohydrate load reaching the large intestine. This could increase microbial growth rate and lead to increased fecal nitrogen excretion as wheat bran inclusion rate increased (Bierman et al. 1999; Erickson et al. 2002). These results agree with those of other researchers who reported increased fecal N excretion as corn bran replaced corn at 15 and 30% of dietary DM in diets for finishing cattle (Erickson et al. 2002).

Nitrogen retention values in this study ranged from 27.6 g d⁻¹ for the control to a maximum of 29.5 g d⁻¹ for the 24% wheat bran diet. These values compare favourably with the observed daily weight gain of the heifers used in this trial. Spanghero and Kowalski (1997) stated that 20 g of retained N per day will lead to 1 kg of body weight gain. Heifers in this trial averaged 0.9 to 1.1 kg per day of body weight gain throughout the trial.

4.4 Conclusion

The results of this study indicate that the replacement of barley grain with wheat bran had no effect on rumen pH or NH₃-N and particulate and fluid passage rate. However, acetate concentration increased in a linear fashion as the wheat bran inclusion level increased. The replacement of barley grain with wheat bran had marked effects on apparent nutrient

digestibility. Overall, DM and OM digestibility decreased linearly as wheat bran inclusion rate increased, while the digestibility of NDF and ADF decreased in a quadratic fashion. Gross energy digestibility decreased linearly with wheat bran inclusion rate, while DE content tended to decrease in a quadratic fashion. Inclusion of wheat bran increased excretion of N in the feces in a quadratic fashion, with the largest increase being seen at 8% wheat bran inclusion levels and the maximum value seen at 24% inclusion of wheat bran.

The results from this trial indicate that dry rolled barley can be replaced with wheat bran with no adverse effects on rumen fermentation parameters. However, inclusion of wheat bran caused a linear decrease in diet dry matter digestibility as well as a quadratic decrease in digestibility of both neutral and acid detergent fibre. These results suggest that animals are unlikely to maintain performance when wheat bran is included in barley-based backgrounding diets.

5.0 GENERAL DISCUSSION

The research conducted in this thesis was designed to evaluate wheat bran derived from abrasion milling prior to ethanol production as a feed for backgrounding cattle. Two trials were conducted. Trial 1 was designed to evaluate performance and real-time ultrasound carcass characteristics of steers fed wheat bran and/or condensed liquid whey as a replacement for barley grain in backgrounding diets. The inclusion of condensed liquid whey at 4.6% of diet DM had no effect on any measured performance or ultrasound parameter. No significant wheat bran x condensed liquid whey interaction was found. The inclusion of wheat bran at 14 or 28% of diet DM had no effect on average daily gain of backgrounding steers. However, the inclusion of wheat bran led to increased dry matter intake and an increased feed:gain ratio (decreased feed efficiency). When compared to the diet containing no wheat bran, cattle consumed 8 and 10% more feed daily on the 14 and 28% wheat bran diets, respectively. This led to a feed:gain ratio that was 9 and 14% higher, respectively, in cattle fed these diets relative to cattle fed the control diet containing no wheat bran. Calculated diet NE_g was reduced by 8 and 13% compared to the control, when wheat bran was included at 14 and 28% of diet DM. Ultrasound carcass traits including *longissimus dorsi* area and subcutaneous fat were unaffected by treatment. Based on the data attained from Trial 1, rolled barley is a superior feedstuff to wheat bran due to the negative affect that wheat bran has on feed efficiency and diet NE_g . However, calves consuming wheat bran were able to sustain the same average daily gain as calves consuming barley, thus if wheat bran is priced appropriately, it can be cost effective to include it in rations for backgrounding calves.

These results are not surprising when one looks at the NE_g of wheat bran compared to that of barley. The NRC (2000) states that barley has a NE_g of 1.40 Mcal kg^{-1} and wheat bran has a NE_g of 1.03 Mcal kg^{-1} . This lower energy value of wheat bran when compared to barley grain can be attributed to the high NDF and ADF and low starch content of wheat bran. The wheat bran used in this trial contained 41.7% NDF and 15.8% ADF which is 22.6% higher in NDF and 8.4% higher in ADF than barley grain. The starch content of wheat bran was 33.9% as compared to barley which contained 58.5% starch. These results are supported by the findings of Trial 2 where it was found that digestibility of both DM and OM decreased in a linear fashion as wheat bran was added to diets. This decrease in DM and OM digestibility explains why calves in Trial 1 had to consume more feed to gain the same amount of weight when wheat bran was included in diets. However, looking at dietary NDF content alone, it is somewhat surprising that calves were able to increase intake as wheat bran inclusion levels increased. Calves were consuming 1.1 to 1.2 percent of body weight as NDF which is at the level which Mertens (1987) states that NDF will start to limit feed intake. However, wheat bran is a very fine material with a particle size of 0.52 ± 0.12 mm. Fibrous feeds with a small particle size generally travel through the rumen at a faster rate, however no difference in rumen passage was seen in the current trial (Robinson et al. 1987; Uden et al. 1988). Along with this, in Trial 2 it was shown that digestibility of NDF and ADF of the total diet decreased in both a linear and quadratic fashion respectively with the largest drop seen at 8% inclusion of wheat bran and minimum digestibility at 16% inclusion. Again, this decrease in fibre digestibility explains why calves in Trial 1 had decreased feed efficiency when fed wheat bran as opposed to barley grain. Also supporting performance results from Trial 1 is the fact that in Trial 2 gross energy digestibility was decreased in a linear fashion as wheat bran was included in diets while diet digestible energy content tended to decrease in a

quadratic fashion as wheat bran was included. Both of these parameters support the lower calculated NE_g and reduced feed efficiency observed in Trial 1. Trial 2, showed no treatment differences in intake when measured as $kg\ d^{-1}$ or as a percent of body weight as a result of wheat bran feeding. These results agree with data from several studies (Hess et al. 1996; Singh et al. 1999; Dhakad et al. 2002) all of which found that intake was not changed when measured as a percent of body weight or as $kg\ d^{-1}$.

Rumen fermentation parameters measured in Trial 2 exhibited a diurnal pattern which is expected with twice daily feeding (Appendix A Figures, 1, 2, and 3). Feeding wheat bran had no effect on rumen pH. All diets had an average rumen pH greater than 6.3 and spent less than 4 h d^{-1} under the threshold for mild acidosis (pH 5.8). Volatile fatty acid results showed that fermentation patterns were typical of high forage diets in which little to no acidosis is expected with a mean pH of 5.8 to 6.5 and a relatively high acetate to propionate ratio (A:P was 3.1 to 3.5 in the current trial). The fine particle size of wheat bran may also explain why rumen pH was not elevated on wheat bran diets. Small particle size does not stimulate chewing and therefore less saliva is secreted and no extra bicarbonate enters the rumen as it would if more physically effective fibre was fed. Also, as expected when starch is replaced with fibrous compounds, acetate concentration increased in a linear fashion as wheat bran inclusion rate increased. Rumen NH_3 -N was not affected by treatment. However, rumen NH_3 -N for all treatments was in the optimal range for microbial fermentation. Passage rate of both the particulate and fluid phase out of the rumen was unaffected by treatment. Particulate phase passage rate decreased numerically as wheat bran was added to diets. Although wheat bran is of a smaller particle size than other fibrous feedstuffs, this did not cause it to have a shorter rumen retention time.

The inclusion of wheat bran had marked effects on nutrient digestibility. As discussed DM, and OM digestibility were decreased in a linear fashion as wheat bran was included. This is likely due to the fact that wheat bran is higher in NDF and ADF and lower in starch than barley grain. The particle size of wheat bran may also be a factor, as its small particle size may cause it to pass from the rumen too quickly for microbes to degrade it. Digestion of both NDF and ADF was decreased in diets containing wheat bran. This could occur for several reasons, the first being the small particle size of wheat bran causes it to pass from the rumen too rapidly for NDF and ADF to be degraded by microbes. Second, the amount of indigestible NDF in wheat bran is not known, and this could also contribute to decreases in NDF digestibility.

The final objective of this thesis was to determine the quantity of nitrogen excreted and retained when wheat bran is included in diets. Nitrogen retention values observed in this trial corresponded to values representing 1.1 to 1.2 kg of daily gain. As wheat bran was included in diets, fecal N excretion was increased. However, there were no effects on total N excretion, urinary N excretion or N retention. This increase in fecal N excretion has positive implications for the environment as it can lead to reduced N volatilization.

Although the inclusion of wheat bran in diets for backgrounding cattle caused increased intake and decreased feed efficiency and dietary NE_g , cattle were able to maintain the same average daily gains as cattle consuming a barley-based backgrounding diet. Intake and performance results from the feedlot trial are supported by the results of the metabolism trial, including the decrease in digestibility of DM, OM and fibre and the numerical decrease in passage rate. The results of these two trials clearly show that for wheat bran to be effectively included in diets for cattle it must be lower in price than barley grain. A brief economic analysis is listed in Appendix B based on the performance of animals from Trial 1. Wheat bran is a

relatively new by-product that is not widely available for use in animal rations. Therefore for the purpose of this economic analysis it was assigned the same price as the barley purchased for the trial. When calves were fed diets containing wheat bran it cost 4 and 9% more per kilogram of gain in the 14 and 28% wheat bran diets, respectively. This illustrates that for wheat bran inclusion to be feasible it must be priced lower than barley grain.

Further areas of research:

1. Quantification of the indigestible NDF portion of wheat bran;
2. Further study of the effects of wheat bran on dry matter intake; and
3. Omasal sampling to quantify passage rate, microbial protein synthesis and digestibility of nutrients.

6.0 GENERAL CONCLUSION

Feeding wheat bran alone or in combination with condensed liquid whey in backgrounding rations at levels of up to 28% in a small pen feedlot study had no negative impacts on average daily gain, or lean or fat growth as measured by real-time ultrasonography. The inclusion of condensed liquid whey had no effect on any measured parameters and no wheat bran x condensed liquid whey interaction was found. However, dry matter intake was increased in diets containing wheat bran which led to a decrease in feed efficiency and lower calculated diet NE_g in diets containing wheat bran. This decrease in efficiency was due to the decreased DM, OM, NDF, ADF and GE digestibility in diets containing wheat bran. However, parameters of rumen fermentation including total VFA production, rumen NH₃-N, rumen pH and particulate and solid passage rate were not affected by inclusion of wheat bran at levels up to 32% of dietary DM. Fecal nitrogen excretion was increased by feeding wheat bran. Further research is necessary to determine the repeatability of the effect of wheat bran inclusion on dry matter intake.

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8.0 APPENDICES

Appendix A. Effects of replacement of barley grain with wheat bran on VFAs, rumen ammonia-N and rumen pH

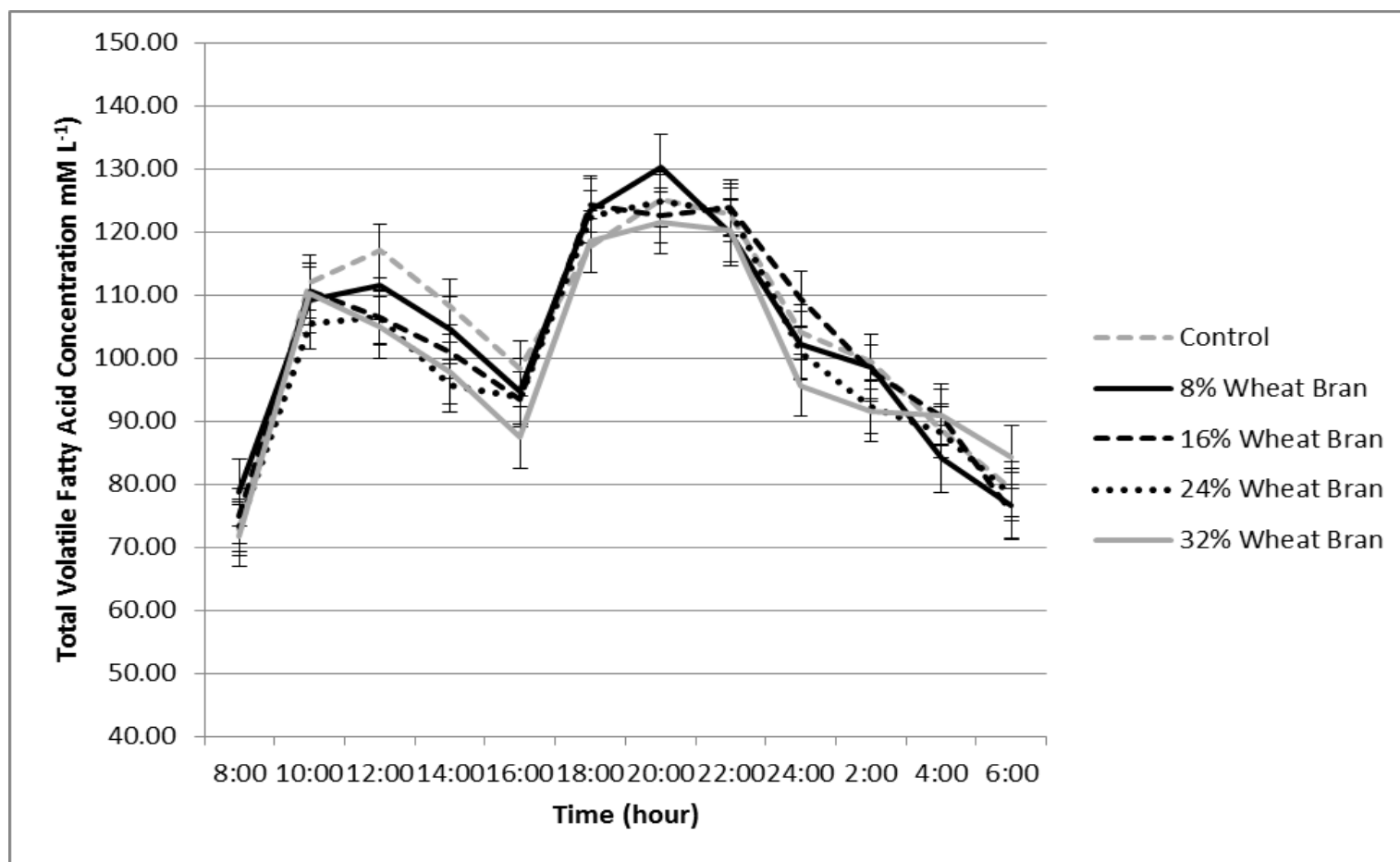


Figure A.1. Effect of replacing barley grain with graded levels of wheat bran (8, 16, 24, and 32%) on the total volatile fatty acid concentration (mM L⁻¹) over a 24 h feeding period

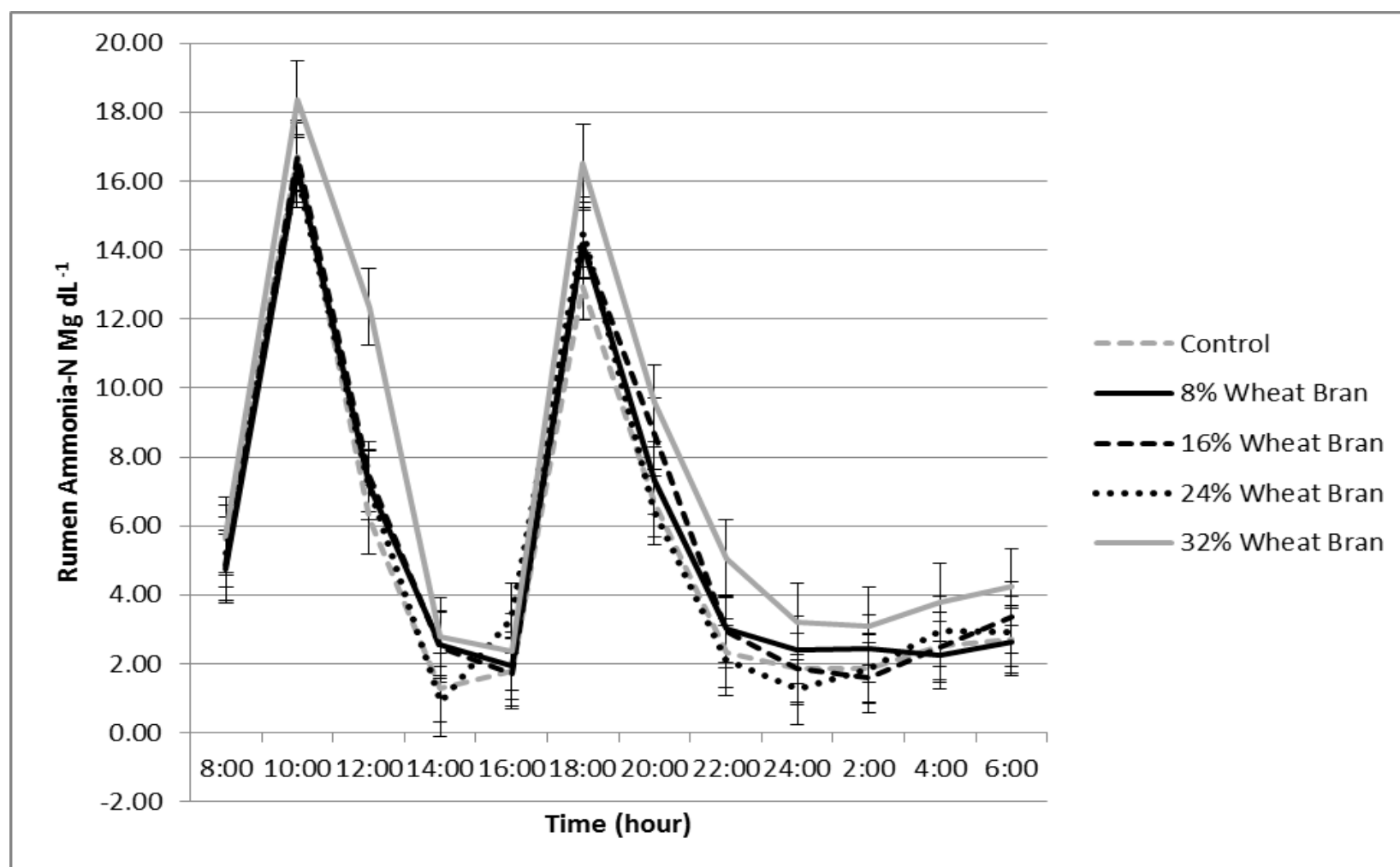


Figure A.2. Effect of replacing barley grain with graded levels of wheat bran (8, 16, 24, and 32%) on rumen ammonia-N levels over a 24 h feeding period

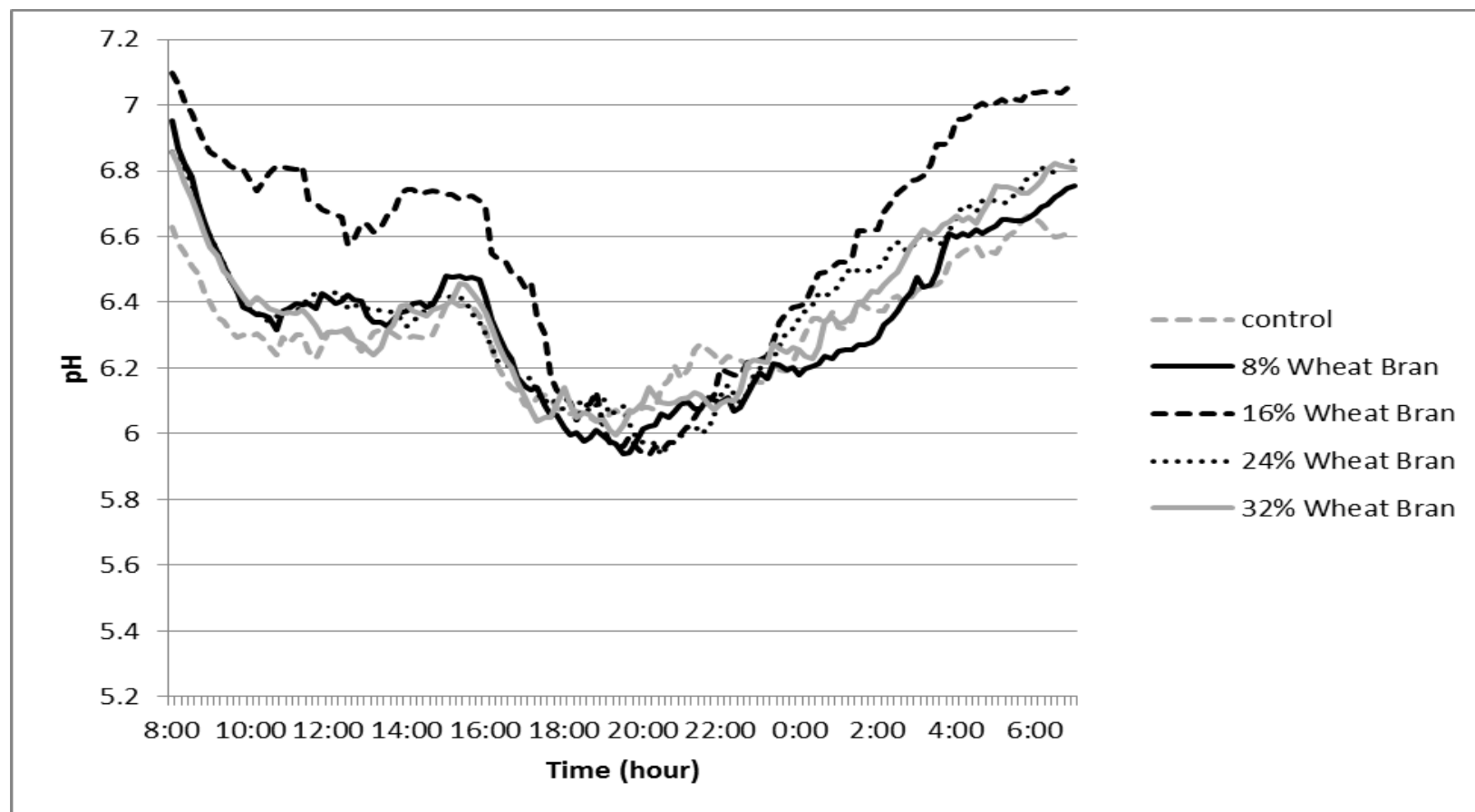


Figure A.3. Effect of replacing barley grain with graded levels of wheat bran (8, 16, 24, and 32%) on rumen pH of heifers using indwelling pH probes averaged over a 23 h feeding period

Appendix B. Economic Analysis

A brief economic analysis was conducted using the animal performance data gathered above. The price of barley grain purchased for the trial was \$135 t⁻¹, the price of hay was \$117 t⁻¹, the price of silage was \$27 t⁻¹ and the cost of processing was \$69.92 per calf. For the purpose of this economic analysis wheat bran was valued at the same price as barley as abrasion milled bran is not available for commercial sale as of yet. All costs were calculated for the 90 day period cattle were on trial.

Table B.1 The effects of replacing barley grain with wheat bran on the cost of backgrounding calves over a 90 day period

	Treatment		
	Control	14% wheat bran	28% wheat bran
Feed cost of grain (\$/kg)	0.64	0.67	0.70
Total feed costs (\$/animal)	78.93	81.79	82.65

Appendix C: Effects of debranning using a lab scale Satake mill on composition of wheat bran and debranned feedstock

Introduction

There has been only limited work on debranning cereal grains for the purpose of ethanol production (Sosulski and Sosulski, 1994). Debranning can be done to varying degrees. Depending on the amount of the kernel removed, the composition of both the bran by-product as well as the wheat entering the fermentation process will differ (Sosulski and Sosulski, 1994; Sosulski et al. 1997). For an integrated feedlot/ethanol facility, a level of debranning that optimizes the efficiency of fermentation as well as the performance of the cattle would be desirable. By debranning grain on a small scale and measuring the proximate composition of both the by-product and the debranned grain one can make inferences about the feeding value of the bran as well as about how much ethanol plant throughput will increase.

Small scale work has been conducted to determine the affects of debranning on ethanol yields as well as composition of grain after debranning, but not on how the composition of wheat bran changes as grain is debranned to different levels (Sosulski and Sosulski, 1994; Sosulski et al. 1997). The objective of this experiment was to determine how the composition of wheat bran would change as wheat was debranned at 0, 5, 10 and 15%.

Materials and Methods

Debranning

A small Satake mill with an abrasive stone (40 grit size) was used to debran wheat (AC Andrew) to three different levels: 5, 10 and 15% of kernel removal. Preliminary work was done prior to the start of the experiment to determine how long grain must be debranned to remove the

desired amount of the kernel. In order to determine this, grain was weighed before and after milling to determine how much of the kernel weight had been removed in the mill.

Grain was then run in batches; 1500 g of grain was considered one batch. The grain was debranned 50g at a time (capacity of the machine). All of the debranned grain as well as the by-product were collected from each batch and a representative sample was taken for lab analysis. Three batches were debranned for each level of debranning.

Lab Analysis

The original grain, the debranned grain and the bran by-product were analyzed for dry matter (AOAC method 930.15), crude protein using a nitrogen conversion factor of 6.25 (AOAC method 984.13), neutral detergent fibre with sodium sulphite and alpha amylase (AOAC method 2002.04), acid detergent fibre (AOAC method 973.18), ether extract (AOAC method 920.39), and starch.

Results and Discussion

Wheat

As wheat is debranned to deeper levels, as expected, starch content of the remaining grain increased as NDF and ADF content decreased (Table C.1, Figure C.1). This is in agreement with previous literature that also found starch content of grain to increase after debranning. This is significant for ethanol plants as starch throughput will increase.

Table C.1 Composition of AC Andrew wheat debranned to 5, 10 or 15% compared to composition of original wheat (0)^x

	Treatment			
	0	5	10	15
<i>Nutrient (% DM basis)</i>				
Dry matter	88.59	89.22	88.68	88.73
Crude Protein	10.27	10.25	10.12	9.64
Neutral detergent fibre	14.10	10.05	9.90	8.38
Acid detergent fibre	2.88	2.05	1.76	2.32
Ether Extract	2.35	3.08	2.31	2.39
Starch	56.59	60.94	60.80	63.63

^xWheat samples were composited across batches to attain a representative samples (n=1)

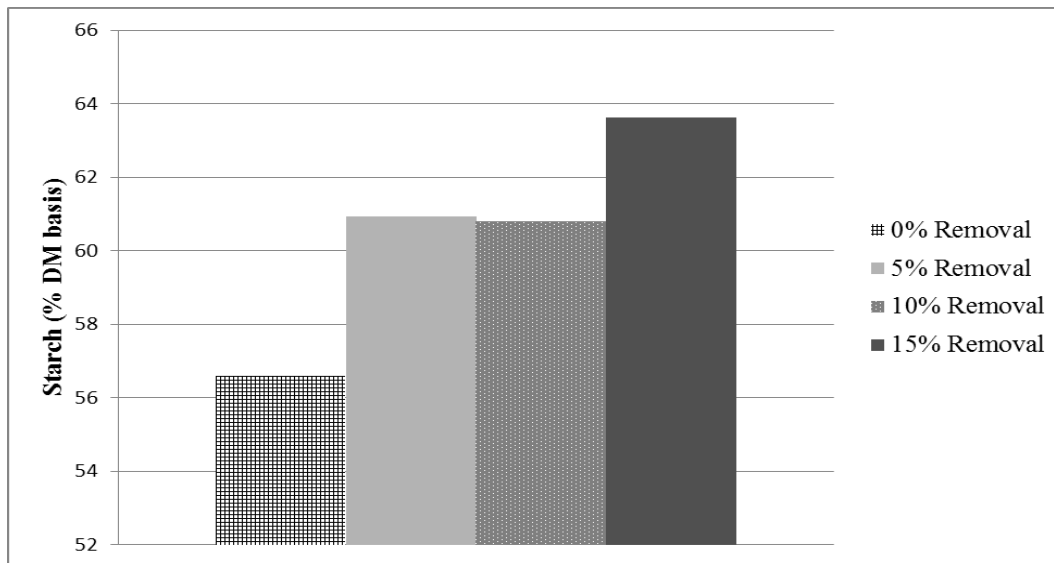


Figure C.1 Starch content of wheat debranned to 0, 5, 10 or 15% of kernel removal

Wheat Bran

Similarly to the wheat feedstock, as grain is debranned to a deeper level the starch content of the wheat bran also increases ($P < 0.01$) (Table C.2, Figures C.2 and C.3). This is because more of the starchy endosperm is being removed in the debranning process. Neutral detergent fibre content of wheat bran is decreased ($P < 0.0001$) as wheat is debranned to higher levels. This can be explained because at low levels of debranning only the outer pericarp layers

of the wheat kernel which are high in NDF and ADF are being removed while at higher levels of debranning this NDF and ADF in the bran becomes diluted by starch.

Table C.2 Composition of bran from wheat debranned to 5, 10 and 15% of kernel removal

<i>Nutrient (% DM basis)</i>	Treatment			SEM	P-value
	5% ^x	10% ^x	15% ^x		
Dry matter	89.34	89.5	89.4	0.17	0.84
Crude protein	12.6a	13.6b	13.4b	0.12	<0.01
Neutral detergent fibre	46.5a	32.8b	26.7c	0.64	<0.0001
Acid detergent fibre	14.3a	11.8b	9.0c	0.46	<0.01
Ether extract	4.6a	4.7b	4.3a	0.07	<0.01
Starch	18.4a	28.9b	35.5c	0.50	<0.01

^x n=5

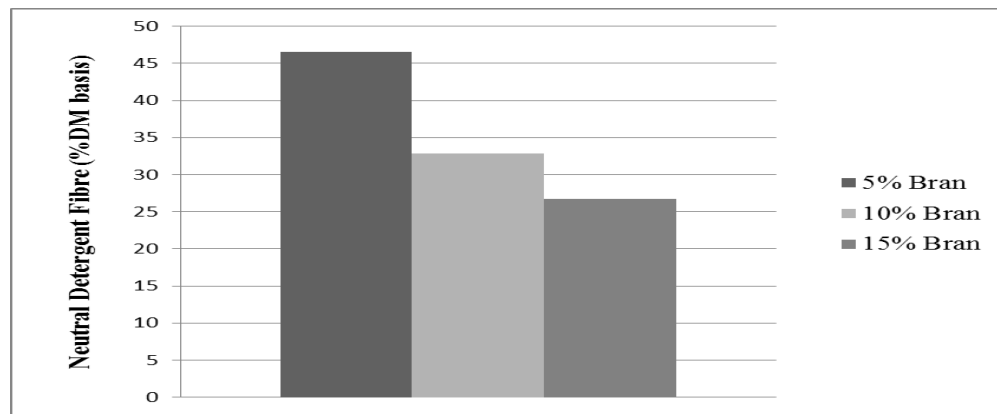


Figure C.2 Neutral detergent fibre content of bran from wheat debranned to 5, 10 or 15% of kernel removal

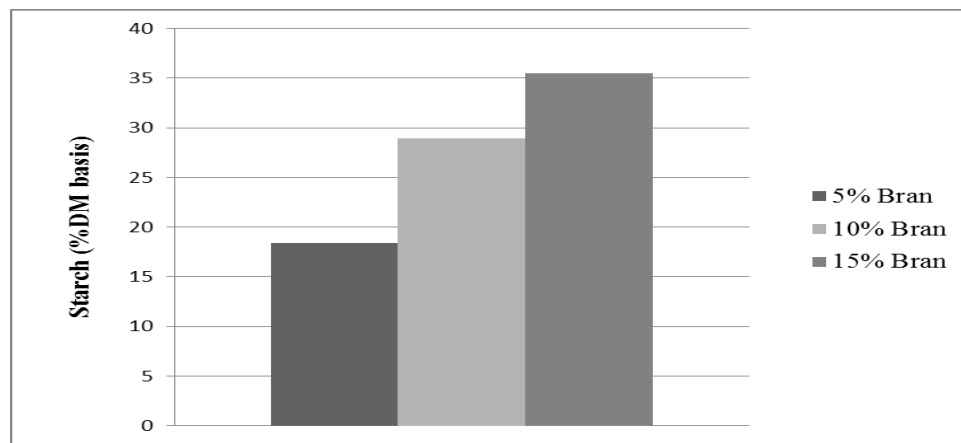


Figure C.3 Starch content of bran from wheat debranned to 5, 10 or 15% of kernel removal

Conclusion

This data tells us that as debranning is done to a greater extent the starch content and crude protein content of the bran is increased ($P < 0.05$) and the NDF and ADF content is decreased ($P < 0.05$). Therefore, bran from debranning done to higher levels will possibly sustain performance more similar to that of high starch concentrates like barley or corn. However, the small particle size of the bran, combined with higher starch levels may cause other feeding problems, such as acidosis. Debranning to deeper levels would not benefit stand alone ethanol plants as too much starch would be lost in the bran, however for an integrated feedlot/ethanol facility an optimal level to maximize both feeding value of the bran and ethanol production is desirable.